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SOME NOTES ON THE BULKING OF ACTIVATED SLUDGE AS OBSERVED AT THE TENAFLY, NEW JERSEY, SEWAGE TREATMENT PLANT. JULY-AUGUST, 1931

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July-August, 1931.

I. Progress Report on Chemical and Physical Aspects of Bulking.
By Emery J. Theriault, Principal Chemist.

II. Biological Study of the Bulking of Activated Sludge at Tenafly, New Jersey.
By W. C. Purdy, Special Expert.

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Stream Pollution Investigations Station
Cincinnati, Ohio.

November, 1932.

PROGRESS REPORT ON CHEMICAL AND PHYSICAL ASPECTS OF "BULKING"

As observed at Tenafly, N.J., July 15 to August 10, 1931.

Emery J. Theriault, Principal Chemist.

Introduction

Studies of the phenomenon of "bulking" in the activated sludge process of sewage treatment were undertaken in accordance with the program of research laid out at the conference of consultants held here in Cincinnati, April 30 to May 2, 1931. The preliminary survey to be described in this memorandum was completed in the interval from July 15 to August 10 (Bureau Orders of July 1, 1931: Station Orders of July 15, 1931.)

With a view to obtaining first-hand information regarding the nature of the problem, arrangements were made, with the approval of the New Jersey State Department of Health, for a visit to the activated sludge plant at Tenafly, N.J. The selection of this particular plant was based on the recommendations of Mr. George W. Fuller, Consultant, to the Public Health Service. The plant is of recent construction and embodies such features of design and operation as may be expected in a well-equipped sewage treatment plant. The plant is under the immediate supervision of a competent operator and, in addition, it continues to receive the attention of its designers, Fuller and McClintock, Consulting Engineers, New York City, through daily telephonic reports and through frequent inspections by one of their staff experts, Mr. W. Donaldson. From the operating viewpoint, therefore, the plant may be regarded as exceptionally favored. Other reasons for the selection of this particular plant for study were the continuity of records of plant performance, the proximity of other treatment plants and the hearty co-operation of the city officials (Hon. Guy C. Foster,

Mayor; Prof. George A. Kipp, Superintendent of Schools; Clinton H. Fuller, Chief Plant Operator).

Complete equipment for chemical and physical tests was shipped from the Cincinnati laboratory and laboratory working space was provided in the modern high school building of the borough of Tenafly.

Previous Investigations

Data obtained in previous studies of the Tenafly plant have been summarized in Tables I. to V.

Values obtained on July 18-19, 1928, by Dr. Willem Rudolfs, Chief, Department of Sewage Research, New Jersey Agricultural Experiment Station, are presented in Table I and the more recent results obtained during the months of May and June, 1931 by Mr. A. J. Fisher, The Dorr Company, are presented in Table II.

Routine tests and other records of plant operation covering the months of July, August and September are presented in Tables III., IV. and V. A transcript of these data was furnished to the writer through the courtesy of Mr. W. Donaldson of Fuller and McClintock.

In the discussion which follows use will be made of these data in estimating the strength of the raw sewage, the quality of the effluent obtained and the methods of plant operation.

(Insert Tables I. to V.)

Nature and Strength of the Raw Sewage

On the basis of the oxygen demand and suspended matter results given in Table I., it would appear that the raw sewage delivered to the Tenafly Disposal Plant is of the ordinary domestic variety, in accord with the purely residential character of this suburban community. This view is sustained by the more extensive and more recent data reproduced in Table II. The average value of the 5-day oxygen demand of the raw sewage for the month of May and the early part of June was 101 p.p.m.

Trouble had been experienced at the plant at some time prior to the survey from the discharge of highly deleterious wastes from an illicit distillery. Full assurance was given to the writer by officials of the borough of Tenafly that this source of disturbance to plant operations had been definitely removed. The same opinion, based on chemical tests for sugars, was also expressed by the chief chemist of the Hackensack Water Company, who are vitally interested in the performance of the Tenafly plant. At the time of the survey, therefore, such "bulking" as was observed could not be ascribed to carbonaceous wastes although previous "bulking" may have been aggravated from this cause.

Quality of the Effluent

As to the quality of the final effluent, an unusual degree of purification is secured, irrespective of plant conditions, by a secondary treatment of the clarifier tank effluent through sand beds followed by heavy chlorination. (See bacteriological results given in Table I.) As to the effluent from the clarifier tanks themselves, a high degree of clarification is indicated by the average of 11 p.p.m. for the suspended matter which passed over the weirs during the month of July (Table III. Column 16). It will be noted, however, that some relatively high values are included in this general average. For the month of August the corresponding figure was 22.7 p.p.m. (Table IV., Column 16). The maximum figure reached was 162 p.p.m. on August 14 when bulking was experienced to an unusual degree.

A sewage effluent with a suspended matter content of 10 p.p.m. or less would ordinarily be rated as excellent; the effluent would still be classed as "Good" when the suspended matter content was between 10 and 20; and it might be regarded as fair with values ranging between 20 and 30.

Another indication of the quality of the plant effluent is furnished by the oxygen demand values given in Table II. under the heading "B.O.D., 4". A 5-day oxygen demand value of around 20 p.p.m. as observed during the first half of May, may be regarded as indicative of a fair degree of purification. Values of 10 p.p.m. or less, as observed during the second half of May and the first part of June should be regarded as excellent.

Methods of Operation

In general, the most important item of plant control relates to the balance which must be maintained between the volume of the incoming sewage and the volume or weight, of returned sludge. Primary considerations in the adjustment of this ratio are as follows:

1. As ample amounts of sludge are always available for recirculation, it might appear possible to add a safe excess of this adsorbent at all times so as to insure complete removal of organic matters from the incoming sewage. In practice, however, it may be impossible to maintain optionally large amounts of activated sludge in a sewage treatment system.

For the first five days of September (Table IV.) the settleable solids at the aeration tank outlet averaged around 40 per cent by volume or 400 ml. per liter. This is a relatively high figure. The corresponding average value for the suspended matter was around 0.21 per cent or 2100 p.p.m. For the next five days the suspended matter content remained fairly constant at the somewhat lower figure of 1900 to 2000 p.p.m. This result, however, was only obtained at the expense of increasing the settleable solids to the extraordinary figure of 60 per cent or over. Under these conditions it would clearly have been impossible to maintain a predetermined figure of, say, 3500 p.p.m. for the suspended matter without first securing a decided improvement in the settling qualities of the sludge. Rational methods of securing such improvement are not now available.

2. The present tendency in plant operation is to recirculate the minimum amount of sludge consistent with obtaining a fair effluent as

judged by analytical or other consideration. A practical reason for this method of operation is that there is less of "bad" sludge to be handled when "bulking" and other difficulties are encountered. The amount of returned sludge is generally based on its volume as settleable solids in the sludge-sewage mixture or else, more rarely, on its weight as suspended matter in the same mixture.

With particular reference to the Tenafly plant it is seen from Table III. under "Returned Sludge" that during the month of July the percentage of sludge by volume in the aeration tanks held closely to an average figure of 9.9. As shown in Table IV. this figure was approximated during the early part of August. On August 14, however, "bulking" occurred and the sludge volume for the balance of the month was doubtlessly influenced by that condition. The general average for August was 19.5 per cent, the maximum reached being 40 per cent on August 15. A figure of 10 per cent may be regarded as relatively low and a figure of over 25 per cent would ordinarily be accounted as correspondingly high.

3. A more valid reason for operation on a low sludge-sewage ratio is the necessity for the maintenance of aerobic conditions. One rule of plant operation, therefore, is to recirculate an amount of sludge such that a positive test for dissolved oxygen can always be obtained in the sludge-sewage mixture. It is doubtful, however, whether accurate methods are now available for the determination of dissolved oxygen under such extreme conditions of test.

As shown in Table III. the average values for dissolved oxygen obtained at the Tenafly plant during the month of July were 1.6

and 0.65 p.p.m., respectively, at 8:30 A.M. and 11:30 A.M. The corresponding values for the month of August (Table IV.) were 2.1 and 0.53 p.p.m. It will be noted that the dissolved oxygen content of the 11:30 A.M. sample was 1.0 and 0.8 p.p.m., respectively, on August 14 and 15 when heavy "bulking" was experienced. These values are decidedly higher than the general average of 0.53 for August in samples collected at the same hour.

4. It has been shown in previous studies (Hagenbale, Theriault and Hommon, 1934, Public Health Bulletin No. 192, revised, pp. 23-24) that the ratio between the volume and the weight of activated sludge is a good semi-empirical measure of sludge condition as evidenced by the clarity of the effluents obtained and other considerations. The significance of this ratio is as follows: Let the volume of returned sludge in the aeration tanks be fixed by operating or other conditions at 15 per cent, corresponding to a figure of 150 ml. per liter for settleable solids (S S). If the suspended matter (S M) content of the sludge-sewage mixture is, say, 1500 p. .m., then the ratio of the suspended matter to the settleable solids is S M/S S = 1500/150, 10. For a given sludge this ratio could not be doubled by a twofold increase in the volume of added sludge as the ratio would then be 3000/300 = 10, as before. If the suspended matter content remained constant, a change to a higher ratio could only be accomplished by a gradual improvement in the settling qualities of the sludge. Although rational methods are lacking for the adjustment of the S M/S S ratio to a favorable figure, this ratio nevertheless does serve as a guide to various plant operations.

Considerable importance is attached at the Lemafly plant to

this S M/S S ratio where it is regarded as the "condition index" of the sludge and defined as the quotient, multiplied by 100, of the suspended matter divided by the settleable solids, both expressed as percentages. Thus, on July 1 (Table I. Columns 10, 11 and 17) the suspended solids is given as 0.24 per cent, corresponding to 2400 p.p.m. The settleable solids, after standing for 30 minutes in a 100 ml. cylinder, was 19 per cent, or 190 ml. per liter. The suspended-matter-settleable-solids ratio is S M/S S = 2400/190 = 12.6. The "condition index" is $\frac{100 \times 0.24}{19}$ = 1.26. The "condition index" values given in Column 17 of Tables III., IV., and V. should therefore be multiplied by 10 in order to obtain the S M/S S ratio as defined above. The factor of 100 is presumably introduced into the computation of the "condition index" in order to obtain index values in the neighborhood of unity, corresponding to 10 on the S M/S S scale. A "condition index" above unity is regarded as an indication of good sludge and of correspondingly good plant behavior. "Bulking" is generally expected when the "condition index" drops below unity.

Experimental Studies

As already shown, it was possible to obtain a reliable picture of plant conditions from various sources. Owing to limitations of time and personnel, the experimental studies were therefore concentrated on the purely research aspects of the problem to the necessary sacrifice of otherwise desirable information regarding the strength of the raw sewage, the quality of the effluents, the degree of nitrification accomplished and other routine items of sewage analysis. It is recognized that, in a more extended study, additional personnel should be provided so as to obtain a complete record of plant performance.

For the purpose of correlating the present study with a previous study of activated sludge plants (Public Health Bulletin No.132) use was made of the suspended-matter-settleable-solids ratio.

As items of major interest, not ordinarily included in sewage examinations, particular attention was paid to the immediate oxygen demand of the sludge-sewage mixture and to the dissolved oxygen content of the aerated mixture.

Samples of the sludge-sewage mixture for the determination of the suspended-matter-settleable-solids ratio were collected from both the inlet and outlet ends of one of the two duplicate aeration tanks. The point of collection of the inlet sample for the first week was at the riser from which the freshly mixed sludge and sewage are delivered into the tank. As lime is also added at this point, this sampling station was later changed to a point 3 feet away from the riser in order to secure a more representative sample. The sample from the outlet end of the tank was collected at a point where the sludge-sewage mixture is ready to pass into the clarifier tank. No difficulty should be experienced in securing a representative sample at this point.

In consideration of the putrescibility of the sludge sewage mixture, no attempt was made to composite these samples over an extended period of time. For the purpose at hand the sewage plant was regarded merely as a convenient source of sludge so that the procedure of collecting catch-samples is not open to the same objection that might be offered in the case of examinations of raw sewage.

Analytical Procedure

The suspended matter content of the sludge-sewage mixture was determined at the plant itself on the thoroughly shaken samples by the prompt removal of a suitable portion, generally 10 ml., with a blunt ended pipette. This sub-sample was immediately filtered through a previously weighed asbestos-gooch crucible. The suspended matter was usually dried for one hour at 103° C. although this period of drying was occasionally overstepped. Tests were also made on the supernatant liquor after 15 minutes of settling.

The settleable solids were determined at the High School Laboratory using 1000 ml. cylinders instead of smaller cylindrical vessels so as to avoid a "capillary tube" effect. The sample in one gallon bottles was first thoroughly mixed and then rapidly poured into the cylinder and the time was noted. Following an initial condition of haziness in the upper part of the cylinder, it was generally possible to observe a reasonably definite margin between the settled solids and the supernatant liquor within five minutes after the start of a test.

A period of settling of 30 minutes was adopted as standard although numerous readings at other time intervals were also made.

The procedure adopted in determining the oxygen demand of the sludge was essentially as described by Theriault and McNamee in Reprint No. 1480 to Public Health Report. (Experimental Studies of Natural Purification in Polluted Waters. VI. Rate of Disappearance of Oxygen in Sludge.)

Dissolved oxygen in supernatant liquors was determined by a modification of the Winkler method described in Supplement No. 90 to Public Health Reports.

Suspended Matter in the Aeration Tanks

As shown in Table VI. the suspended matter content of the sludge-sewage mixture collected at the inlet to the aeration tanks ranged from 1335 p.p.m. on July 23 to 2860 p.p.m. on August 3 when the tests were discontinued. The low figure of 1335 p.p.m. was probably due to a partial stoppage of the sludge return line. The high figure of 2860 p.p.m. corresponds to an actual increase in the sludge-sewage ratio due to the shut down for purposes of inspection of one of the two aeration tanks, so that the entire sewage flow, beginning August 31, was passed through a single unit. Other values for the suspended matter content at the inlet of the aeration tank do not depart appreciably from the general average of 1900 p.p.m. The allowable error in this determination is about 5 per cent, corresponding to 100 p.p.m. for the magnitudes in question.

The suspended matter content at the outlet of the aeration tanks did not depart appreciably from the general average of 2260 p.p.m. excepting the relatively high figure obtained on August 3 due to a change in operation.

(Insert Table VI.)

The difference between the suspended matter content at the inlet and outlet of the aeration tanks is 360 p.p.m. on the basis of the average values obtained. In part this difference may be credited to the removal of solids from the sewage. To some extent also this relatively great difference may be due to variations in the adjustment of the sludge-sewage ratio to the volume of incoming sewage. It should

also be noted in this connection that the sample collected at the inlet to the aeration tanks consisted of day sewage (9 to 10 A.M.) plus sludge. As the period of aeration is approximately 7 hours, the corresponding sample collected at the same time from the outlet of the aeration tank was composed of aerated night sewage (2 to 3 A.M.) plus sludge. On the whole it would, therefore, appear that sludge-sewage ratio is maintained within reasonably close limits.

The suspended matter content of the supernatant liquor from samples collected at the inlet to the aeration tanks may be compared with the corresponding values for the raw sewage given in the last column of Table VI. The basis of comparison, however, is admittedly unsatisfactory as the values given for the raw sewage are average values over a 24-hour period instead of analyses of the incoming sewage at the time of collection of the sludge-sewage mixture. Although there is some evidence that a considerable reduction in suspended matter may occur within a few minutes it must be concluded that little importance can be attached to this limited series of observations. The expectancy in these experiments was that, under standard conditions, the extent of removal of suspended matter from the incoming sewage on its admixture with the returned sludge might be taken as a measure of the clarifying power or condition of the sludge.

The suspended matter content in the supernatant liquor from the outlet end of the aeration tank is a rough indication of the maximum degree of clarification to be expected under ideal conditions of quiescense during settling. Values of 0.0 p.p.m. on July 22 to 23 are probably due to the unavoidable error in weighing the small quantities of sus-

pended matter which were undoubtedly present with an ordinary analytical balance. The sharp increase in non-settleable suspended matter from July 25 to 28 is associated with "bulking" and the use of lime on those days. The indication is that "bulking" at this plant may also occur under quiescent conditions of settling in laboratory containers so that the loss of solids from the clarifier tanks cannot very well be credited to faulty design or to such other factors as sudden variations in the rate of pumpage, etc. Further confirmation of this view is to be found in the biological observations made by Mr. Purdy.

The Settleable Solids in the Aeration Tanks

Numerous determinations of settleable solids in samples collected from inlet and outlet ends of the aeration tanks have been summarized in Table VII. The main points brought out in these experiments will be discussed with reference to the plot in Fig. 1 of the representative set of observations of July 24 on a sample collected at the inlet of the aeration tanks.

The upper curve in Fig. 1 was obtained by plotting the volume of settled sludge against the time of settling using freshly collected sludge (1 hour old). Practically the same results were obtained when the test was repeated two hours after the collection of the sludge. After 5 1/2 hours, however, there was a distinct tendency for more rapid settling and this tendency was accentuated when the sludge had stood overnight (26 hours) without aeration. In this case, however, the supernatant liquor was far from clear. A conclusion drawn from these experiments is that the settling characteristics of the sludge are not greatly affected by a delay of two hours before examination.

(Insert Table VII. and Fig. 1)

It will be noted also that most of the settling occurs in the first 5 minutes and that the slope of the curve is still changing rapidly after 15 minutes of settling. For this reason a 30-minute period of settling is probably to be preferred as readings are then made along a comparatively flat portion of the curve. With some sludges complications due to gas formation may be expected if the test is unduly prolonged.

In fact, close correlation may be shown to exist between the 15-and 30-minute readings so that a 15-minute period of settling is sometimes used in plant operation where quick readings are desired.

The S M/S S Ratio of the "Condition Index" of the Sludge.

Data pertaining to the suspended-matter-settleable-solids ratio or the "condition index" of the sludge have been collected in Table VIII. using values already given in Tables VI. and VII.

The general averages for the S M/S S ratios of samples collected at the inlet and outlet ends of the aeration tanks are, respectively, 12.5 and 12.1 Excepting the relatively high value of 19 obtained July 27 for the inlet sample, this similarity of results is also borne out within experimental and sampling errors when individual results are compared. It will be noted also that the S M/S S ratio is quite independent of the actual amount of sludge present. Thus the figures for suspended matter and for settleable solids at the outlet end of the tank are generally higher than those obtained at the inlet end, although the S M/S S ratio is somewhat the same in each case.

(Insert Table VIII.)

As no account has been taken of the period of detention in the aeration tanks it cannot be concluded that the S M/S S ratio remains unchanged when the sludge is subjected to a prolonged aeration of about 7 hours. In securing information of this character it would be necessary to compare samples collected from the inlet end of the aeration tanks at, say, 9 A.M. with samples taken 7 hours later or at 4 P.M. from the outlet end. Correspondingly the 9 A.M. samples from the outlet end of the aeration tanks should be related to samples collected at 2 A.M. from the inlet. It was not possible to institute such a schedule of analysis although the desired information might be of value in estimating the

true significance of the S M/S S ratio.

For purposes of comparison the ratios obtained in a previous study of activated sludge plants (Public Health Bulletin No. 132, Revised, pp. 22-24) have been partly reproduced in Table IX. The following description of these results is of interest:

> "At the Houston south side plant, where the highest ratio, 42, was obtained, the sludge was characterized as "very good sludge" and the plant was in very good working order. At the Houston north side plant, where the average ratio was 23, some difficulty had been experienced with the sludge just previous to the survey. The sewage treated at this plant is not much stronger than at the south side plant, and the final effluent, although very highly purified, was not quite as good as that from the south side plant. At San Marcos, where the ratio is about 8, the sewage receives some preliminary treatment before reaching the activated-sludge plant, by which a good part of the suspended matter is removed. The 5-day oxygen demand of the effluent from this plant is about twice as great as that of the Houston plants, and the 5-day oxygen demand of the plant influent is only about one-half as great. This plant could not be said to be working as efficiently as the larger Houston plants. The Sherman plant was admittedly out of order, and the sludge could very well be characterized as "bad" sludge. The ratio derived is about 5."

(Insert Table IX.)

The classification of the sludge as "Very Good", "Good", "Fair" or "Bad" was based on the degree of purification accomplished in terms of reduction in oxygen demand, suspended matter removal, nitrification and other indicators of plant performance. Although based on examinations of sludge at only 4 plants, the correlation is striking. In comparison with the results obtained at Tenafly it would appear that, if this more or less arbitrary classification holds, the sludge at that plant should be classed as "Fair" to "Good" in quality at the time of the survey.

With particular reference to "bulking" it is noteworthy that as shown in Table X., the addition of lime as a corrective for that condition was commenced on Sunday, July 26, at 8:30 P.M. and continued with few interruptions until Wednesday, July 29. Prior to July 26 the S M/S S ratio in the outlet sample had ranged from 12 to 16. Observations were not made on Sunday 26, but on the three succeeding days the values obtained were, respectively, 9.7, 9.7 and 7.6. The ratio then increased to 14 on July 30 and bulking ceased. This ratio then decreased to 11 on July 31 when the entire flow of sewage was diverted to a single aeration tank. Although the amount of sludge added to the incoming sewage was increased somewhat when this change in plant operation was made, the S M/S S ratio nevertheless decreased to 8.3 on August 1 and lime was ag in added as a corrective for "bulking" which occurred overnight. There is evidence in these experiments of close correlation between "bulking" and a sudden decreasd in the S M/S S ratio to values below 10.

(Insert Table X.)

Attention is now directed to the "condition index" values given in the last column of Table VIII. The values were taken from the operating data given in Tables III. and IV. and in each case the values were multiplied by 10 in order to place them on a comparable basis with the S M/S S ratios. The general average for the "condition index" is 10.2 and this value would not be greatly affected by the omission of the two Sunday results (8.8 and 12.7) included in the "condition index" values. On the whole there is good agreement between the two sets of values. Apart from differences of sampling, the tendency towards relatively low values for the "condition index" may be partly ascribed:

1. To the use of a longer period of drying in the determination of suspended matter in examinations made by the plant operators, the tendency being towards lower results for the suspended matter.

2. To the use of 100 ml. cylinders instead of the 1000 ml. cylinders used by the writer. It is believed that this difference of technique might lead to relatively higher results for settleable solids.

With reference to the "condition index" values, given in Table IV. it is seen that "slight" bulking occurred on August 7 and 9 when the "condition index" was respectively. 0.68 and 0.80, corresponding to 6.8 and 8.0 on the S M/S S scale. On August 13 the relatively high value 1.13 (or 11.3) was observed and on the following day "heavy" bulking was encountered although the condition index had only dropped to 0.79 (or 7.9). Again in the last week of the month of September (Table V.) excellent results as regards clarification appear to have been obtained without the use of lime although the "condition index" was always below unity. In fact, for the entire month of September, the general average for the "condition index" was only 0.58 (or 5.8 on the S M/S S scale) corresponding to the "bad" sludge observed at Sherman (Cf. Table IX.) It is to be noted, however, that the heaviest "bulking" was observed from September 8 to 13 when the "condition index" was in the neighborhood of 0.3 (See column 17, Table V.)

On the whole it must be concluded that the use of the S M/S S as an index of the condition of the sludge appears to be amply warranted by the above discussion of results obtained at the Tenafly plant. In the present state of development of sewage analysis it is probably the most

readily applied criterion of sludge condition and, indirectly, of plant performance. This index may be used to anticipate the onset of a period of "bulking". It does not furnish any information, however, regarding the nature of the difficulty and it does not afford any clue to remedial measures. If a relatively low value of, say 5 is obtained for S M/S S ratio, there is no indication as to how this figure might be increased to a supposedly more favorable value such as 15 or 20.

The development of more informative tests for sludge condition will be discussed in a separate report on a proposed program of sewage research.

The Oxygen Demand of Activated Sludge

Considerable difficulty was experienced in determining the oxygen demand of the sludge under field conditions. The most reliable values obtained have been summarized in Table XI. together with other results obtained here in Cincinnati using sludge from the artificial channels. Average values obtained by Grant, Hurwitz and Mohlman at the Chicago North Side plant have also been included.

On July 25 the 1-hour demand of the sludge-sewage mixture collected at the inlet to the aeration tanks was 102.1 p.p.m., as determined in a specially constructed aeration apparatus without dilution of the sludge. The corresponding 22-hour oxygen demand of the same sample was 320 p.p.m. The ratio of the 22-hour demand to the 1-hour demand is only 3 (see last column of Table XI.) There was no visual evidence of bulking on July 25 when these values were obtained and the S M/S S ratio of 13 gave no indication of prospective difficulties. Heavy "bulking", however, occurred on the following day, Sunday, July 26. On Monday, July 27, the 22-hour demand of the sludge-sewage mixture had risen to 514 p.p.m. Thereafter there was a steady improvement in clarification until the use of lime was discontinued on July 29. It is noteworthy that the 1-hour and also the 22-hour oxygen demand of the sludge sewage mixture decreased progressively from July 26 to July 30. This progressive improvement is also shown by a progressive diminution in the "milligrams of oxygen required per gram of sludge per hour", until a figure of 15 had been reached on July 30.

(Insert Table XI.)

In comparison with sludge taken from the artificial channels here at the Cincinnati laboratory, it is seen that the ratio of the 22-hour to the 1-hour oxygen demand was only 8 in the channels. The minimum values reached by the Tenafly sludge-sewage mixtures were 10 to 12. The S M/S S ratio of 44 for the Cincinnati sludge is comparable with the results given in Table IX. for the "very good sludge" observed at the South Side Plant in Houston. In terms of "milligrams of oxygen per gram of sludge" it is seen that the oxygen requirement of the Cincinnati sludge was only 9 in comparison with a minimum figure of 15 observed at Tenafly.

Another basis of comparison is offered by the results obtained at Chicago. The oxygen requirement of 7 milligrams of oxygen per gram of sludge is approximately half of the lowest value observed at Tenafly. It will be noted, however, that approximately twice as much sludge, in terms of suspended matter by weight, was carried at Chicago as at Tenafly. If the strength of the raw sewage is somewhat the same the conclusion appears warranted that, at best, the Tenafly sludge carries a load of organic matter which is double that carried at Chicago.

In retrospect, it would now appear that as an index of sludge condition or of overloading considerable importance may attach to the immediate oxygen demand of the sludge-sewage mixture. With a sludge mixture of fairly constant composition it may be possible to use the 1-hour demand as a measure of the putrescibility of the sludge. More properly the ratio of the 22-hour or 24-hour demand to the 1-hour demand might be used as an index. If the immediate demand is very low, this ratio would be relatively high.

A more extended series of observations would obviously be required to establish the validity of this suggested interpretation of results. There is some evidence, however, that a forecast of "bulking" based on an increase in the immediate oxygen demand of the sludge might be made even when other indicators of sludge condition, such as the S M/S S ratio, fail to register any marked change. It is clear, however, that the oxygen demand test itself could not furnish any indication as to whether the increase in immediate oxygen requirements was due to underaeration (anaerobiosis) or to overloading.

The Dissolved Oxygen Content of Sludge-Sewage Mixtures.

The determination of dissolved oxygen is of obvious importance in plant control as a direct measure of under-aeration and, indirectly, of other related difficulties among which "bulking", conceivably, should be included. As there are numerous objections on the score of accuracy to the present methods for determining dissolved oxygen in sludge-sewage mixtures, considerable time was devoted to this item of research with results which, on the whole, are purely negative.

The usual procedure in determining the dissolved oxygen content of a sludge-sewage mixture is to collect a large sample by dipping below the surface of an aeration tank with a suitable container such as a bucket. The sample is brought to the laboratory and when the sludge has settled sufficiently a portion of the supernatant liquor is siphoned into a glass bottle. Dissolved oxygen is then determined on this sub-sample by the customary Winkler procedure, with or without the use of modifications designed to obviate interference from the relatively large amounts of dissolved or colloidal organic matters which are generally present. Sludge particles also interfere seriously with the Winkler method and it is for that reason that the sludge mixture must first be settled before proceeding with the test. As a rule, however, some sludge particles are inevitably present in the sample even after settling.

From previous considerations it is reasonable to assume that the oxygen demand of sludge-sewage mixtures collected from the Tenafly aeration tanks may at times exceed 1 milligram of oxygen per liter of sludge per minute. Now it is known that the solubility of dissolved oxygen is about

9.0 milligrams per liter at 20° C., or 7.6 milligrams at summer temperatures of 30° C. It may also be assumed that a period of settling of 10 to 15 minutes is generally required before a test can be made. Under these conditions it is obvious that complete exhaustion of the dissolved oxygen may be expected before the test for this substance is actually applied to the clarified supernatant liquor. The difficulty in question will be aggravated when the test is applied to samples collected from separate re-aeration tanks where the oxygen demand of the concentrated sludge may readily exceed 10 milligrams of oxygen per minute. In this case the oxygen supply may even be exhausted before the sample is brought to the laboratory and before settling has occurred to an appreciable extent.

The procedure of adding sterilizing agents to the sludge-sewage mixtures at the time of collection is inaffective as the loss of oxygen is not primarily due to biological activity but rather to the immediate or purely chemical oxygen demand of the sludge.

A modification of the Winkler method recently proposed in Supplement No. 90 to Public Health Reports gave reasonable results with aerated supernatant liquors but failed utterly when sludge particles were present.

In this connection it should be pointed out that fictitious values for dissolved oxygen may readily be obtained unless special precautions are taken in the transfer of the supernatant liquor from the original sampling container to the bottle actually used for the dissolved oxygen determination. When the presumably anaerobic supernatant liquor

is simply siphoned into a bottle it is reasonable to suppose, and readily demonstrated by actual experiment, that an increase of 1 or 2 p.p.m. in dissolved oxygen may occur as a result of re-aeration.

An apparent oxygen content of several parts per million may also be obtained when tests are conducted in the presence of nitrites, which may arise from the decomposition of nitrates when the sludge-sewage mixture is allowed to stand anaerobically or which may be originally present in sludge-sewage mixture collected at the outlet end of the aerations tanks. The Rideal-Stewart or permanganate modification should be used in such cases. In certain experiments an error of 3 to 4 p.p.m. was noted from this source.

Using a mercury displacement device for the collection of samples for the dissolved oxygen determination and applying the permanganate modification of the Winkler method, it was repeatedly found that dissolved oxygen was completely absent from the supernatant liquor of sludge-sewage mixtures which had been well-aerated prior to settling. In some instances this result was checked by a direct determination of the oxygen demand of the sludge-sewage mixture based on an analysis of the air above the sample, so as to eliminate any interference due to the sludge.

On the whole the problem of determining dissolved oxygen in aeration tanks and especially in re-aeration tanks remains an unsolved research problem. The matter is of considerable importance in sewage plant control and it will be discussed more fully in a separate memorandum on suggested lines of future sewage research.

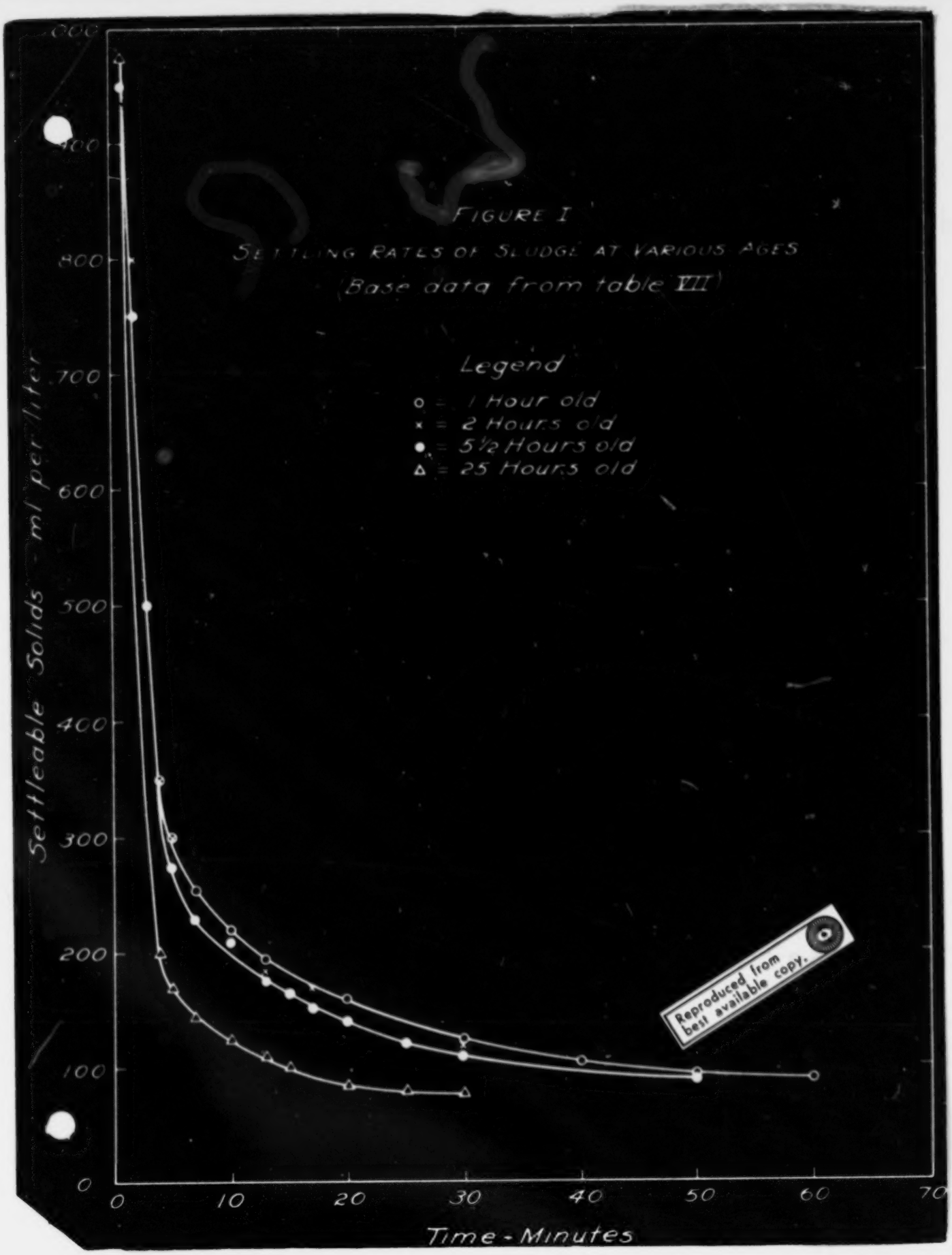
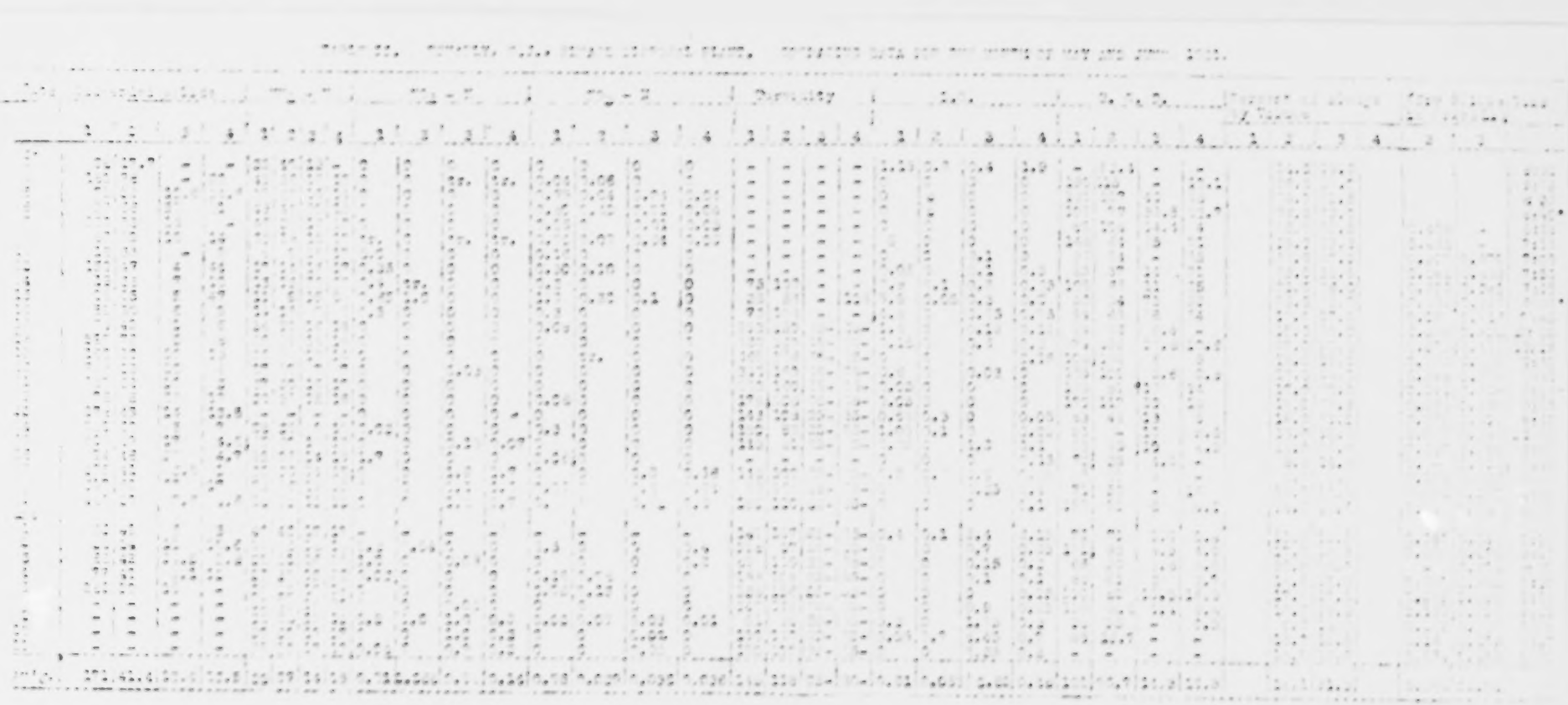


FIGURE I
SETTLING RATES OF SLUDGE AT VARIOUS AGES
(Base data from table VII)
Legend
o = 1 Hour old
x = 2 Hours old
● = 5½ Hours old
Δ = 25 Hours old
Settleable Solids - ml per liter
900
800
700
600
500
400
300
200
100
0
0
10
20
30
40
50
60
70
Time - Minutes
Reproduced from best available copy.



30.A

TABLE I. DATA EXPLAINED BY THE VERY LARGE [illegible] OF THE SEWAGE TO [illegible] BY THE AMOUNT OF SEWAGE APPLIED (Lt. Gallons Applied / Sq. Ft.)

Sampling point	6:15 P.M.	9:15	12:15	2:15 P.M.	3:15	5:15	6:15	7:15	9:15	10:15	11:15 P.M.	1:15	4:15	6:15	7:15	8:15 A.M.
Influent	205	210	180	170	185	210	215	210	210	190	180	185	190	195	200	210
Aer.tank	310	340	310	370	310	295	285	290	310	305	300	310	310	315	320	330
Clarifier	10.7	14.3	16.7	15.3	10	10	10	9.3	12.3	11.3	11.3	11.3	11.3	11.3	11.3	11.3
Sand bed	4.2	11.5	10.3	7.5	10	10	3.3	10.0	10.3	5.3	4.3	5.3	5.3	5.3	5.3	5.3
Final	3.2	3.3	2.5	7.2	2.3	3.2	3	3.2	3.2	3.3	3.3	3.3	3.3	3.3	3.3	3.3
Influent	41		56	60	54	61	54	54	54	54	56	56	60	70	70	70
Aer.tank	4120		4010		4200	4000		4200		4200		4200		4200	4200	4200
Clarifier	30	28	22	18	22	31	22	20	18	17	17	20	18	14	15	17
Sand bed	0.3	0.2	0.3	0.7	0.7	1.1	0.7	0.7	1.0	1.0	2.0	0.7	1.2	0.4	1.7	
Effluent	1.0	1.2	1.3	0.3	0.4	0.2	0.3	0.3	0.4	1.0	1.0	1.0	0.3	0.3		
Influent	0.00		0.00		0.02		0.05		0.0		0.0		0.0			
Aer.tank	.010		.01		.015		.01		.015		.005		.015			
Clarifier	.015		.01		.01		.015		.02		.02		.015			
Sand bed	.010		.015		.015		.015		.015		.01		.015			
Final	.015		.015		.01		.02		.015		.01		.015			
Influent	9700	100000	93000	90000	7000	90000	9100	8500	8100	8000	6500	6000	4800	5000	5400	5800
Aer.effl.	18500	13000	4100	30000	17000	90000	94000	97300	80000	17000	4850	6000	5740	7000	6400	5745
Clar.effl	5000	6000	7150		800	3100	1000	3800	1700	1900	2000	1400	1800	3500	4480	1516
Sand	50	150	130		170	75	90	300	120	70	105	105	615	43	134	111
Final*	18	18	0	0	2	9	9	0	4	2	0	0	14	14	0.07	0.073

* B. coli final effluent per 100 c.c.

[illegible]

[illegible]

[illegible]

TABLE VI. SUSPENDED MATTER DETERMINATIONS.

Date 1931	Sludge-sewage Mix. At Inlet End	Sludge-sewage Mix. At Outlet End	Supernatant Liquors At Inlet End	Supernatant Liquors At Outlet End	Raw Sewage (3)	Remarks
	Suspended Matter - P.P.M.					
Jul. 22	1740	2300	92	0.0	92	
23	1335 (1)	2370	72	0.0	100	
24	1810	2040	91	0.0	94	
25	1670	2260	112	9.5	184	
26	--	--	--	--	--	Bulking
27	1940	2020	110	15	152	"
28	1780	2180	64	48	138	"
29	2140	2120	20	12	90	No bulking at 7 A.M.
30	1880	2320	--			
31	1670	1910	--			
Aug. 1	2200	2250	--			
3	2850 (2)	2860 (2)	--			
Av'g.	1900	2260	80	12	130	

(1) Low figure probably due to stoppage of sludge return line.

(2) High figure due to change in method of operation.

(3) Values taken from column 6, Tables III. and IV. based on weighted composite, 6 samples at 4-hour intervals.

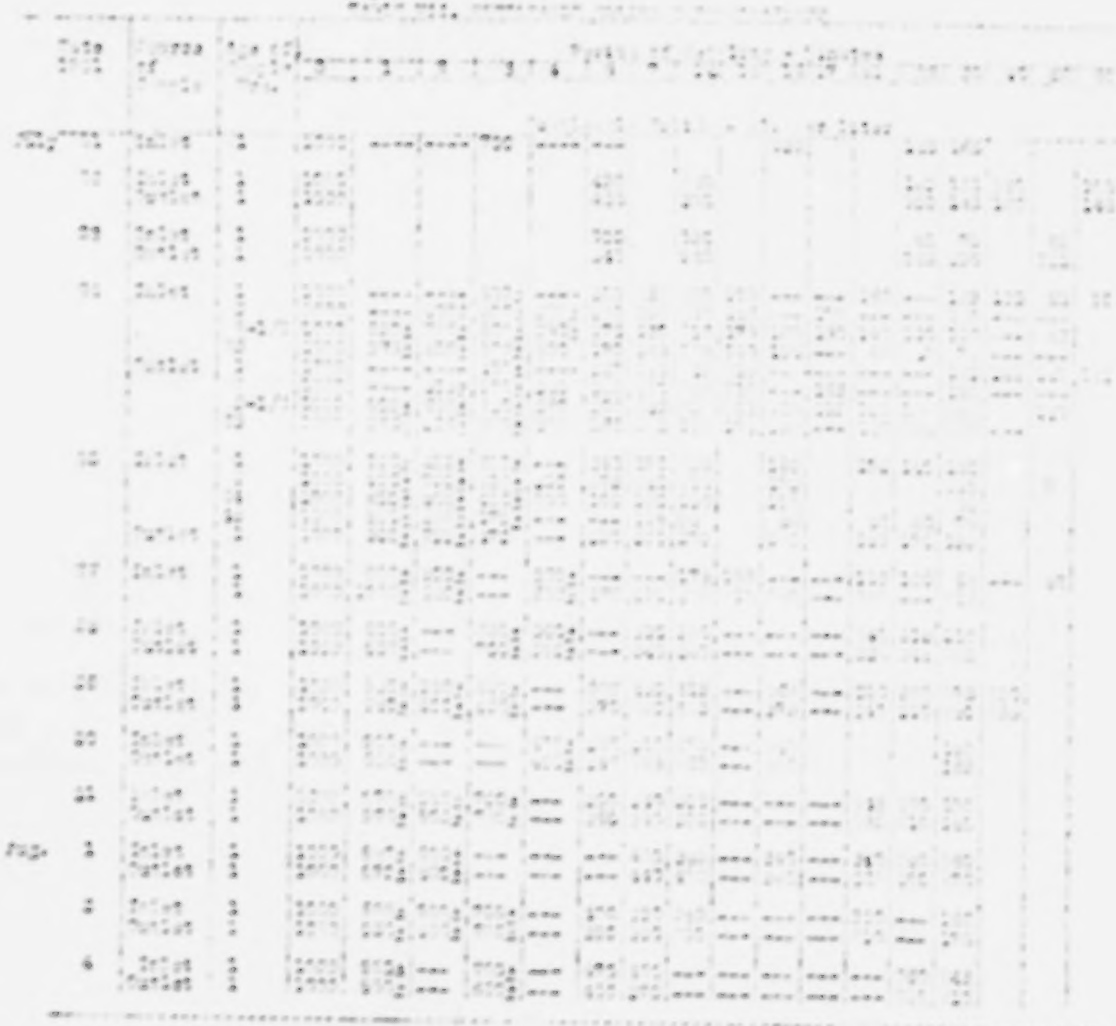


TABLE VIII. RATIO OF SUSPENDED MATTER TO SETTLEABLE SOLIDS

Date 1931	At Inlet: Susp. Matter p.p.m.	At Inlet: Sett. Sol. 30' ml./liter	At Outlet: Susp. Matter p.p.m.	At Outlet: Sett. Sol. 30' ml./liter	Ratio: SS/SS Inlet	Ratio: SS/SS Outlet	"Condition Index" x 10 (See Table)	Remarks
July 22	1740	160	2300	185	11.	12.	11.7	
23	1335	70	2370	150	19.	16.	12.6	
24	1810	125	2240	160	14.	14.	13.3	
25	1670	130	2260	155	13.	14.	11.3	
26	--	--	--	--	--	--	3.8	Lime added 8:20 P.M. to 12 Mid.
27	1340	95	2090	215	19.	9.7	9.4	Lime added 11:30 A.M. to 12 Mid.
28	1780	210	2180	225	8.5	9.7	9.0	Lime added all day
29	2140	275	2120	280	7.8	7.6	8.0	Lime added 1 A.M. to 7 A.M.
30	1930	180	2320	165	10.	14.	10.6	
31	1670	190	1910	180	8.8	11.	8.3	Aeration tank #2 out of service
Aug. 1	2220	260	2250	270	8.5	8.3	8.9	Lime added 11 A.M. to 12 Mid.
2	--	--	--	--	--	--	12.7	Sunday
3	2660	160	2860	170	16.	17.	10.0	
Averages	1901	169	2264	196	12.5	12.1	10.2	

TABLE IX. THE SM/SS RATIOS OBTAINED AT OTHER PLANTS
(AVERAGE VALUES TAKEN FROM PUBLIC HEALTH
BULLETIN NO. 132, REVISED. PAGE 23)

Plant	Number of observations made	Suspended matter p.p.m.	Settleable Solids 30' Ml./Liter	SM/SS Ratio	(Remarks)
		"Very good" sludge			
Houston, South Side	2	232	9745	42	Best results at this plant
		"Good" sludge			
Houston, North Side	6	202	4568	23	Good results
		"Fair" sludge			
San Marcos	2	265	2820	10	Small plant
		"Bad" sludge			
Sherman	4	366	1818	3	Plant out of order

TABLE X. PLANT RECORD OF LIME ADDITIONS (DATA FURNISHED BY C.H.FULLER, CHIEF PLANT OPERATOR.)

1931	Time	Amount	p.H
July 15	6.00 PM	1 bag	
	6.30	1 bag	
	7.00	1 bag	7.6
	8.00	1 bag	8.0
	9.00	1 bag	8.1
	10.00	1 bag	8.2
	11.00	1 bag	8.3
	12.00 Mid.		8.2
	1.00 AM	1 bag	8.1
	2.00		8.1
	3.00	1 bag	8.0
	4.00		8.1
	5.00	1 bag	8.0
	6.00		8.1
	7.00	1 bag	8.1
18	11:30 AM	1 bag	
	12.30	1 bag	
	1.30		8.0
	2.30	1 bag	8.0
	3.30		8.0
	4.00	1 bag	7.8
	4.30	1 bag	7.8
	5.00	1 bag	7.8
	5.30	1 bag	7.8
	6.00		8.1
	7.00	1/2 bag	8.1
	7.30	1/2 bag	8.1
	8.00	1 bag	8.1
	8.30		8.2
	9.00	1 bag	8.1
	9.30		8.1
	10.00	1 bag	8.1
	10.30		8.1
	11.00	1 bag	8.0
	11.30		8.1
	1.30		8.1
	2.30		8.1
26	8.20 PM	1 bag	
	8.40	1 bag	
	9.00	1 bag	
	10.00	1 bag	8.1
	11.00		8.2
	12.00 Mid.	1 bag	
27	11.30 AM	1 bag	
	11.45	1 bag	
	12.00 Noon	1 bag	
	1.00 PM		8.2
	2.00	1 bag	8.1
	3.00		8.1
July 27 Cont'd.	4.00 PM	1 bag	7.6
	5.00	1 bag	7.6
	6.00	1 bag	8.0
	7.00	1/2 bag	8.1
	8.00	1 bag	8.2
	9.00	1 bag	8.1
	10.00	1 bag	8.1
	11.00	1 bag	8.1
28	12.00 Mid.	1 bag	8.1
	1.00 AM	1 bag	8.1
	Well flushed		
	3.00	1 bag	8.0
	4.00	1 bag	8.0
	5.00	1 bag	-8.0-
	6.00		8.2
	7.00		8.2
29	2.45 PM	1 bag	
	3.05	1 bag	
	3.30	1 bag	
	4.30	1 bag	8.0
	6.45	1 bag	
	7.30	1 bag	8.0
	8.30		8.1
	9.00	1 bag	8.1
	10.00	1 bag	8.1
	11.00	1 bag	8.1
	1.00 AM	1 bag	8.1
	2.00		8.1
	3.00	1 bag	8.2
	4.00		8.2
	5.00	1 bag	8.2
	6.00		8.2
	7.00	1 bag	8.2
Aug. 1	11.00 AM	1 bag	
	11.30	1 bag	
	12.00	1 bag	8.1
	1.00 PM		8.2
	2.00		8.1
	3.00		8.1
	4.00	1/2 bag	8.1
	5.00	1 bag	8.1
	6.00	1 bag	8.2
	7.00		8.1
	8.00	1 bag	8.1
	9.00		8.1
	10.00	1 bag	8.1
	11.00	1 bag	8.1
	12.00 Mid.	1 bag	8.1

pH - Phenol red
1 bag = 50 lb.

TABLE XI. OXYGEN DEMAND OF SLUDGE-SEWAGE MIXTURES

Date	Oxygen Demand p.p.m. Period of Incubation (Hrs.) 1	22	45	Suspended Matter p.p.m.	Settleable Solids Ml./Liter	SM/SS Ratio	Milligrams of Oxygen per Gram of Sludge per Hour	O. D. Ratio 22 hrs./1 hr.	Remarks
Tenafly - Aeration Tank Mixture									
1931 July 25	102.1	320	434	1670	130	13	61	3	No bulking
26	—	—	--	--	—	--	--	--	Bulking - Sunday
27	--	514		1840	95	19	--	--	"
28	42.5	407		1780	210	8.5	24	10	"
29	34.4	386		2120	280	7.6	16	11	No bulking at 7 A.M.
30	28.6	341		1880	180	10.	15	12	No bulking
Cincinnati - Channel Sludge									
1929 March	89	731	1000	10000	230	44	9	8	*
Chicago - North Side Plant									
1929 Dec.	26.6	--	--	3800	--	--	7	--	**

* From Public Health Reports 46.1310 (1931) Table 2, Series 19 at 26 to 52° C.

** From Sewage Works Journal 2.240 (1929).

BIOLOGICAL STUDY OF THE BULKING OF ACTIVATED SLUDGE AT TENAFLY, NEW JERSEY.

By W. C. Purdy

Special Expert
U.S.Public Health Service.

U. S. Public Health Service,
Office of Stream Pollution Investigations,
Cincinnati, Ohio.

November, 1932.

40-A

OBSERVATIONS ON THE BULKING OF ACTIVATED SLUDGE AT TENAFLY, NEW JERSEY.

By W. C. Purdy, Special Expert,
U. S. Public Health Service.

The following paper is an effort to state, in a definite way, some of the facts observed during a three-weeks' session with an activated sludge sewage treatment plant where "bulking" was a frequent and troublesome occurrence. The matter is here discussed largely from the biological point of view, and such limitations as are thereby placed upon certain deductions which appear warranted are here and now freely acknowledged. By the same token, however, we submit to the fair appraisal of the reader a goodly array of data, acquired with great care, relative to the actual volume of the nonfungous matter of the floc as compared to the total length of radiating filaments of fungus thereon: (1) when the sludge is settling properly, and again (2) when it refuses to settle, or bulks.

The bulking of sludge defeats in some measure the purpose of the treatment plant and introduces a real hazard into the intended efficiency of such treatment, particularly in such thickly-settled portions of our country as require that the effluent, passing into feeder streams of a given watershed, shall not constitute a threat to the reasonable

safety of some municipal water supply a day or two downstream.

There is no question as to the fact of bulking. It is a very real trouble in a number of activated sludge plants. Nor is there any question, in many of these cases, as to the abundance of fungus meantime, for this also has been reported from many sources. Some treatment plants have but little bulking. Other plants have reported bulking but from causes other than fungus growth. In the plant under discussion, both bulking and the coincident abundance of fungus were outstanding features. This paper is an attempt to state these two facts, together with accessory and supporting data, in such a manner as to set forth the possibility, and also to express the probability that the fungus was a primary cause of the bulking of the sludge as observed by us at Tenafly. Such conditions may or may not obtain at other sewage treatment plants, and such deductions may or may not be warranted in these cases. We desire to emphasize the fact that this paper is based wholly on observations made at the Tenafly plant.

The discussion will be unsatisfactory to many because no definite cause for the growth of fungus is pointed out, and no remedy is suggested, other than the well-known use of lime, for in this brief study we were concerned only with

the fact of bulking sludge, the fact of abundant fungus growth meantime,- and the possible fact of a causal relationship between these two at this particular treatment plant.

It is hoped that one result of the data here given will be to encourage plant operators to use the microscope and to give a half hour, more or less, daily to the inspection of floc from the sludge blanket, to see whether fungus is present to an amount approaching the danger zone. The photographs, with appended explanations, may be a practical help in this matter. It may be possible to prevent bulking more easily than to check it after it is well started, if advance information can be secured. There seems to be a possibility of this in cases where fungus growth is concerned. To meet this possible need, a brief procedure for examination is suggested, with the hope that this will be helpful.

A very large amount of laborious measuring of fungus filaments, and related laboratory procedure, has been necessary in the arrangement of the data here presented. For this exacting work I desire to thank Mrs. Orena B. Stewart, Junior Bacteriologist in our Cincinnati laboratory.

The situation. Bulking of sludge occurs rather frequently in the Tenafly,* New Jersey, activated sludge plant. It

* For details as to the arrangement and working of this plant see article by Wellington Donaldson, in Sewage Works Journal, January, 1932.

was observed that in most cases the bulking sludge at this plant showed the presence of fungus growth, and in accordance with similar conditions known to exist at other plants, it was thought that the fungus might be responsible, in part at least, for the troublesome condition.

In order to ascertain the facts in the case, so far as these might be obtained, a program of intensive study and observation was begun July 21, 1931, and continued until August 4, - a period of almost three weeks. During this period, three well-defined bulkings occurred, affording reasonable opportunity to observe this phenomenon at first hand. Observations were continued and samples were collected daily during almost the entire period, in order to compare the conditions and characteristics of nonbulking sludge with those of the bulking sludge.

Having in mind the reported presence and abundance of fungus at such times as bulking was in progress, we sought to confirm or disprove this report, and to ascertain the locations of such growth in the sewage treatment plant, and to note the stage of treatment of the sewage, also any other conditions that might contribute to the optimum environment which would presumably result in fungus growth in troublesome amount.

The sampling points. The location of sampling points was as follows: (1) the raw, rough-screened, incoming sewage; (2) the return sludge, at a point just before it mingles with the raw sewage; (3) the mingled raw sewage and return sludge as this mixture is discharged from the "riser" pipe to empty into the end of the aeration tank; (4) the sludge at the far end of the aeration tank after presumably 5 hours' aeration, and just before it enters the clarifier tank; (5B) the "sludge blanket," at whatever depth below the water surface the upper layers of this blanket happened to be; (5T) the uppermost portion of the water in this clarifier tank, perhaps 2 or 3 inches below the surface, and being that more or less clarified effluent which continuously escaped over the weir, and passed to the sand beds for further removal of such suspended matter as failed to settle into the sludge blanket.

Representative samples were secured at these sampling points by the use of a long-handled dipper, the sample being poured at once into a 1-ounce bottle and preserved with formalin. In the case of the sludge blanket, which was usually 6 or 8 feet below the water surface, the sample was secured in a bottle attached to a pole, the bottle stopper being withdrawn by a string when sufficiently immersed within the upper portion of the sludge blanket.

Examination of the samples. On arrival at the laboratory (less than one hour after sampling), a portion of the 1-ounce samples was diluted, in order to effect proper separation of the individual flocs, and 1 cubic centimeter of the dilution placed in a Sedgwick-Rafter counting cell. After a rapid survey of cell contents using a low power microscope, further examination was made using a 16 millimeter objective and a 4x ocular which contained a Whipple micrometer disc by which measurements were made of the flocs and of the attached fungus filaments.

Handling of the sample breaks up the larger masses of floc material. These smaller flocs as prepared for microscopic study are usually less than one millimeter in their greatest dimension. In our routine examination we selected five typical flocs, representative as to size, and as to amount of fungus growth. These five were examined in detail, and record was made: (1) of the volume of the floc proper (exclusive of any fungus or other filamentous body that might be attached), (2) of the number of filaments of fungus that apparently grew out from the body of the floc, and (3) of the total or combined length of all these fungus filaments. Having thus examined five representative flocs, the resulting data may be regarded as a fair picture of the conditions which are then prevalent throughout the body of sludge at the sampling point concerned.

The total volume of the floc is ascertained by computation of the several geometric forms of which it is usually composed. These usually approximate cones, spheres, and cylinders. The flocs are not flat, thin flakes. They have many shapes and forms, and it is frequently something of a task to compute their volume with assurance of reasona ble accuracy. With the assumption, however, that they usually have thickness in their various parts approximately equal to the measured diameter,- a matter that we have observed in the examination of a large number of flocs,- the measurement of volume of a given floc may be accomplished with a reasonable degree of accuracy. There seems to be no other available method of ascertaining the approximate volume of the floc proper, exclusive of the attendant fungus filaments, which are frequently very numerous and radiate in all directions from the floc as a center. Centrifuging would obviously fail to give us the desired data because of interference of these fungus filaments, and the unknown degree, if any, to which these filaments would be compressed into small space by centrifuging. It might be possible to ascertain a relationship between the volume of sludge settled by gravity, and the volume settled by centrifuging at a certain rate, presumably sufficiently great to overcome the resistance of the radiating fungus filaments. Thus far we have made no attempt to work out such a relationship in order to

evaluate the volume of the sludge flocs exclusive of the attendant fungus.

Measurement of the radiating fungus threads is greatly facilitated by allowing a diluted portion of the sample to dry on a slide, thus bringing all the fungus filaments into one plane. By using an eyepiece micrometer, as in plankton enumeration, and having the tube-length of the microscope properly adjusted, each filament may be measured and the total or combined length obtained.

It will be observed that this procedure is subject to a factor of error because portions of certain filaments are necessarily covered by the body of the floc, and cannot be seen nor measured. In like manner, such fungus filaments as occupy the upper surface of the floc when dried upon the slide are invisible also, so only those filaments which project beyond the boundary of the floc are capable of being measured. It will thus be seen that such measurements of fungus length as are given in this paper are conservative, to say the least. This factor of inaccuracy, however, is common to all flocs, so the measurements which are recorded possess relative accuracy in consequence.

Expression of results. In casting about for some means of expressing the relative volume of floc-solid together with the total length of the numerous fungus filaments attached

thereto, in the case of a given sample, we presently adopted the method of expressing the floc solid (the volume of the floc exclusive of the attendant and attached fungus) in terms of one entire cubic millimeter, and the attached fungus in terms of linear millimeters, further stated in terms of feet. The reason for this is to visualize to the general reader a relationship that would otherwise be apparent only to those persons who are familiar with microscopic dimensions and microscopic objects. The following example will illustrate:

Five representative flocs from a given sample showed, when measured under the microscope, a total of 0.008 cubic millimeter of floc solid. These same five flocs showed a total length of 16. millimeters of attached fungus filaments. Expressing these same items in terms of 1 entire cubic millimeter for the volume of the floc, we find that this volume of floc is attended by attached fungus whose total length is 6.6 ft.

$$(16.\ \text{mm} \times \frac{1.}{0.008} = 2000.\ \text{mm} \text{ or } 6.6\ \text{ft.})$$

It will be observed that, by this method, the volume of floc solid is fixed (1 cubic millimeter), and the total length of attendant fungus filaments varies, thus giving a reasonably accurate picture of the extent to which the chang-

ing values of growing fungus filaments, radiating in all planes and directions from this floc as a center, may operate, presumably, to increase the floating power of a given volume of floc solid.

Discussion of results. The examination of about 100 samples collected at Tenafly, July 21 to August 4 inclusive, showed a number of outstanding characteristics relative to this fungus growth as observed in various parts of the sewage plant. The data concerned are recorded in Table 1, herewith given. The time interval is divided into three periods of "bulking" and four periods of good sludge actually occurring meantime. General statement of results, and further discussion of certain findings, are herewith submitted:

(1) Fungus was found in the raw sewage in occasional traces only, except for the sample of July 22 when it was found in moderate amount.

(2) Fungus was present in appreciable amounts in all other samples, these including the return sludge, the mixture of return sludge and sewage at the entrance of the aeration tank, the aerated sludge at the outlet of the aeration tank, the sludge blanket in the clarifier, and the effluent passing over the weir of the clarifier.

(3) In nearly every case the floc in samples of effluent passing over the weir showed fungus in larger amount

than did any other samples taken at the same time, in other locations in the sewage plant. (See Table 1, Column 5T). This would indicate the probability that abundance of the fungus enabled floc to float more readily than would have been the case had the fungus been scanty or lacking.

(4) Increased power of the fungus-infested floc to float is further indicated by microscopic examination of the sludge when it is actually bulking. Inspection of Table 1, Column 5B (the sludge blanket) shows that during the bulking period of July 27, the average content of fungus in the sludge blanket, based on the measurement of seven flocs, was 8.0 feet per cubic millimeter of floc solid, whereas the average at the same place for seven samples collected during a preceding nonbulking period of 6 days was only 2.14 feet. In like manner, as shown by the above table, the bulking period of July 29 showed, in the sludge blanket, an average fungus content of 14.8 feet per cubic millimeter, but samples taken the following morning when the sludge blanket was well under the surface showed 8.4 feet of fungus, apparently sufficient for bulking, and bulking did develop the following day, the sludge blanket rising to within 5.5 feet of the water surface, and fungus growth averaging, for this and the day following, 19.4 feet per cubic millimeter of floc solid. On the third day no sample was ob-

tained, and during the next two days (the last days of our observations) the sludge was again normal, averaging only 2. feet of fungus,and the blanket was well settled 8 feet below the water surface.

(5) Further study of the data in Table 1 divided into seven periods, as there indicated, based on the presence or the absence of bulking, shows that there were four periods of good sludge, and three well-defined periods of bulking sludge during this interval. Inspection of Column 5B indicates that, during the absence of bulking (periods I, III, V and VII) the average fungus content in the sludge blanket was 3.1 feet per cubic millimeter of floc solid, while during the three periods of troublesome bulking (periods II, IV and VI) the fungus content in this same place averaged 11.3 feet.

(6) When sludge, in the sludge blanket, is not bulking, but is settling properly, the highest content of fungus is 4.1 feet for period I, 6.8 feet for period III, 8.4 feet for period V, and 2.3 feet for period VII. That is, there seems to be little or no likelihood of fungus-caused bulking so long as the fungus content does not exceed 7 or 8 feet, approximately, according to these data. There seems to be sufficient warrant, however, to regard this as the extreme limit of safety and the border line of the danger zone.

(7) During the three periods (II, IV and VI) of bulking recorded in Table 1, the average fungus content in the bulking sludge (Column 5B) is 11.3 feet. The range of values is from about 5. feet to 23.2 feet. The lower values of 4.9, 5.8, 6., 6.6, and 7.5 feet indicate the possibility of bulking taking place when the fungus content is at or near this "danger zone" point. Such a fungus value was not reached in the nonbulking sludge of period I (see Column 5B) nor of period VII. This value was reached, however, in periods III and V (see Column 5B, July 28 and 30), but in each of these cases the bulking of the preceding day had just been checked by the use of lime.

(8) Bulking of sludge varies considerably in severity,- that is, the attack may be a very pronounced and troublesome one, or it may be mild, and controlled with ease. There may also be cases of near-bulking, in which the sludge blanket does not rise sufficiently high in the clarifier to discharge the suspended matter over the weir with the effluent. A condition of this kind developed July 31. Reference to Table 1 shows that bulking was in progress July 29, when at 4:00 P.M. the sludge blanket was only 1.5 feet under the surface. Lime was used, and the next morning, July 30, bulking had been checked and the blanket was at the safe depth of 8 feet, showing fungus con-

tent, however, of 8.4 feet, which appears to be slightly outside the limit of safety and within the danger zone. Subsequent developments tend to confirm this, for in another 24 hours, July 31, the sludge blanket showed a content of 15.9 feet, indicating bulking, and the blanket had risen to within 5.5 feet of the surface. For some unknown reason its rise was checked though lime was not used, probably because the actual discharge of suspended solids over the weir was only 10 parts per million,(a) whereas during active bulking on the 29th the discharge had reached 17 parts. In another 24 hours (August 1), the blanket was still several feet (4.5) below the surface, the floc showing a rather heavy content (23.2 feet) of fungus, far outside the limits of safety. This was the condition of affairs at 10:00 A.M. The blanket must have risen later this same day, and actual bulking developed as a result, for the plant records(a) show that suspended solids escaping over the weir reached 22 p.p.m., and lime was used. Unfortunately we obtained no sample for the succeeding day, August 2, and at 10:00 A.M. the following day, August 3, the sludge blanket was at the safe depth of 8 feet, and the floc showed less than 2 feet of fungus per cubic millimeter of floc solid, a figure well

(a) Some Notes on the Operation of Sewage Treatment Works, by Wellington Donaldson. Table 1, Sewage Works Journal, Jan., 1932.

within the safety zone. An apparent discrepancy is evident, however, in the fact that the plant records[a] show a heavy discharge of suspended solids (28 p.p.m.) over the weir on this date.

Physical effects of fungus filament. The particle of solid matter, or floc proper, from which radiate many or few filaments of fungus, may be likened to the familiar seed of thistle, or dandelion, or some such plant. To the seed proper is attached an arrangement of radiating and branching filaments, the net effect of which is to increase resistance to the air, thus enabling the seed to float for long distances, even if the air be moving only very slightly. Meantime, if such a seed, with its attendant parachute outfit, be released in air that is entirely motionless, the seed will slowly descend and settle.

Now if we were to clip off a portion of the parachute arrangement, we would most certainly decrease the power of the seed to float. It would settle more readily. If we remove all of the parachute, the seed will be without power to float, and will quickly drop to the ground, even in a light breeze.

In like manner, the floc solid, in the sewage under

(a) Some Notes on the Operation of Sewage Treatment Works, by Wellington Donaldson. Table 1, Sewage Works Journal, Jan., 1932.

discussion, is attended with radiating filaments of fungus. If these be numerous and long, the floating power of the floc is thereby increased. If the filaments are few, or short, the floating power is obviously decreased. If there be no fungus at all, the floc solid will surely settle the more readily, somewhat like the thistle-seed minus its parachute appendage. In the case of the thistle seed, there is obviously an interrelationship, purely physical, between: (1) the weight to be carried (the seed proper), (2) the weight-supporting effectiveness of the parachute in terms of its own surface friction with air, and (3) the amount of air movement required to enable this parachute to sustain the seed and its appendages in the air against the pull of gravity. This is analogous to the "flying speed" of an airplane, so to speak, borrowing a term from modern aviation. Decrease either the speed, or the amount of sustaining friction surface, and airplane or floating seed alike would begin to fall.

In like manner, I believe there is interrelationship, similarly physical, in the case of the sludge floc, involving: (1) the weight of the floc itself, (2) the surface friction (with the water) of certain outgrowths from the floc such as fungus filaments, and (3) the amount of water movement required to keep the floc and its appendages floating, against the pull of gravity. However, the de-

sired objective of the thistle seed is to float, and to be transported a considerable distance from its point of origin,- whereas the desired objective withregard to the sludge floc is to have this settle to the bottom to that degree which will effect separation of these solids from the supernatant liquid. Obviously the presence of fungus filaments on the floc will to some extent hinder such settling.

In the three physical relationships or factors just stated, the velocity of water movement will be nearly or quite constant, inasmuch as the activated sludge process is usually a continuous flow proposition. A second factor,- the weight of the floc solid per unit of volume, stated in terms of its ability to settle in water, will necessarily vary slightly, depending partly on the physical form, whether the floc as such be much expanded and irregular, or whether it be in compact form, with the minimum of surface area exposed to friction. By the same token, the third factor, or outgrowths of fungus filaments or other organisms from the floc solid, will present additional friction surface and consequent resistance to settling proportional to the quantity of this growth present. The amount, therefore, of such growth seems to be the one variable factor in the situation, the velocity of water movement, and the weight of a given volume of floc solid, both being relatively constant.

In considering the probable effectiveness of this additional friction surface added to the floc proper by the growth of fungus, it is to be noted that this added material is in the form of microscopic, usually unbranched, filaments, circular in cross section, and having a diameter of about 1.5 microns. It seems significant also that these filaments grow outward from the central floc not only in various directions but also in various planes, in consequence of which the added friction surface is effective regardless of the changing positions of the floc as a whole. It is impossible to "upset" a floc, so to speak, so that it will settle rapidly in the water sideways, as a wheel-like body might, rendering ineffective a considerable portion of such friction surface as might be provided by radially-arranged filaments in a single plane. On the contrary it seems certain that, in natural floc, the extra friction surface provided by the outgrowing fungus filaments acts equally well as a deterrent of movement in any direction, and is therefore much more efficient than the same amount of surface would be if in the form of a fin or a membrane.

A possible explanation for bulking when fungus is abundant.

Floc, even when dense, and in particles or masses large enough to be individually and easily visible to the unaided eye, is yet very easily diluted and a homogeneous suspen-

sion results, formed chiefly of very small flocs, rather than the former large masses. That is, these masses very readily break up, even when fungus growth is abundant. It seems that the ends of fungus filaments, radiating in all directions from a bit of floc as a center, freely pass between the similar ends of fungus filaments from the surrounding floc particles. Apparently these filaments thus interpass, or intermesh, yet do not become tangled, nor do the filaments from one floc particle become actually attached to another floc particle, thus binding the two together. If the fungus were a branched one, this condition might not obtain,- that is, the intermeshing of the fungus ends might easily result in actual entangling, binding adjacent floc particles into a mass whose parts would separate with difficulty, or perhaps not at all, when the sample is agitated. Perhaps we should be thankful that the fungus usually concerned is an unbranched one. A branching variety might produce a matted, semisolid, inseparable sludge mass or blanket requiring rakes or similar tools for hourly removal to prevent clogging of return lines or of weir.

In view of the evident, untangled condition of the easily-separable sludge flocs even when these harbor extensive growths of radiating fungus filaments, what is the possible or probable connection between this fact and the process of bulking?

The specific gravity of the floc particles is very slightly in excess of that of the water itself, hence these minute submerged masses possess to a large degree the freedom to move in any direction, and they are therefore very easily displaced by any physical push, however slight. It seems possible that the growing fungus filaments, radiating from a given floc and gradually increasing in length, will come in contact with the similar filaments growing from another floc,- or perhaps with the other floc itself. The very slight, yet real pushing force thus created by the mutual expansion of these adjacent fungus-bearing flocs will probably be expressed: (1) by bending aside of the fungus filaments, in order to continue growth in the path of least resistance, this in turn resulting in more or less tortuous filaments interlaced with the similar filaments of surrounding flocs, or (2) by the flocs which are mutually pushed moving farther apart in response to such push.

Of these two possible results, the first would seem to be rendered doubtful by the fact, already discussed, that floc particles separate very readily, even when they are apparently in dense masses and contain a heavy growth of fungus. Moreover the tensile strength* of these filaments

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* A single fungus filament possesses sufficient tensile strength to enable a person to tow a small floc from place to place in the water by using fine forceps. Actual trial with 5 different flocs gave distances of 0.5 inch to 2. inches through which the respective flocs were thus towed by a single filament.

is such as to render improbable the explanation of the easy separation of the floc particles, as above stated, by the breaking of such filaments as are intermeshed or matted.

On the other hand, the second result (that is, the slight moving apart of the flocs in response to the push created by the growing fungus filaments) would seem to be actually aided by the fact that the increasing friction surface of any given floc (due to the lengthening fungus filaments thereon) would most certainly increase the floating power of that floc, the water-movement meantime remaining constant. The floc particle would move slightly in the direction of least resistance, thereby equalizing, for a time, the pressure upon it, and adjacent flocs would behave in like manner. Constant water movement meantime would aid, rather than hinder, such a process as this continuous adjustment to a continuous urge, so to speak, originating from the individual floc because of the continuous outgrowth of the fungus filaments thereon. Each floc merely requires more room than it formerly did, and the inevitable consequence is a general separation of the free-to-move flocs, which movement may be extensive enough to carry these flocs to every portion of water available in a tank, such as the clarifier. Thus the sludge blanket, requiring more room, expands, and in doing so it oversteps the limits of its normal position 7 or 8 feet below the water surface and trespasses into the

relatively clear body of supernatant above it. This diffusion of the blanket is thus secured at the expense, so to speak, of the overlying clear water. The once dense "blanket" becomes a diffuse cloud throughout the tank or clarifier and discharges large amounts of its floc or suspended solids over the weir. The sludge has "bulked."

We believe that the foregoing is a possible and reasonable explanation of the mechanics of bulking, so far as this phenomenon may be due to the growth of fungus filaments, as at the Tenafly plant. It is as if a military company were parading, marching well in the center of the street, in close formation. But on receiving the command to proceed in open formation, the individuals separate from one another until the marching body occupies the street from curb to curb. The parade has "bulked."

Nonsettling suspended matter. There is always a small amount of suspended matter which is too light to settle in the clarifier, even when the sludge is not bulking. This goes over the weir and, as is shown in Column 5T, Period I, the average fungus content is 6.5 feet, while the range of values runs from 3.3 feet to 12.1 feet. In explanation of the apparent inconsistency exhibited by a limited number (seven) of the entries in Column 5T, in that these few samples showed a small content of fungus, less than 6 feet,

and yet this floc floated, and passed over the weir, we may say:

(a) The nonfungous matter of the floc itself may on occasion be sufficiently light in weight and diffuse in structure to enable it to float (and doubtless this is quite frequently the case), and such floating floc may or may not contain outgrowths of fungus filaments, or may contain small amounts only. Such floc, though floating and therefore passing over the weir, would give low results as to fungus content.

(b) Another explanation lies in the fact that under natural operating conditions the floc is easily visible to the unaided eye, being in masses one to three millimeters in greatest dimension. As a matter of fact these masses are made up of many individual flocs loosely aggregated and floating as a frail raft. Some of these flocs have very little fungus, or none at all. A light touch or slight agitation of the water will break up this aggregation into the numerous minute flocs of which it is composed. Such an aggregation is shown in Cut No. 1, while Cut No. 2 shows individual flocs from a sample taken at the same time and place. No. 1 was obtained with elaborate precautions to prevent breaking up of the floating raft, while No. 2 was taken without such precautions, and was subjected to considerable agitation in mixing the sample, and in diluting

on the slide, in order to separate the individual flocs to facilitate examination, sketching and measurement of the attached fungus filaments. Nearly all of our slides were made in this latter manner, and all of our data were obtained from a study of these individual minute flocs, and not from the unbroken larger rafts or masses. Measurement of fungus in these larger masses would be practically impossible.

It is quite possible therefore that some of the samples in Column 5T, for example those of July 22, 23, 25, and 26, which exhibit the apparent inconsistency of floating, though meantime containing insufficient fungus filaments to enable them to float, are merely the result of breaking up these aggregations or rafts, thus exhibiting on the slide to be examined, perhaps side by side, the individual flocs which formerly made up the raft, some of these flocs possessing sufficient fungus growth to enable them to float, and other flocs possessing scant growth, yet enabled to float in the original sample by being enmeshed in the unbroken common raft.

The friction surface added by fungus growth. The actual amount of additional friction surface presented to the water by the fungus filaments may be stated as follows.

A number of filaments (more than a dozen) measured un-

der the microscope show an average diameter of 1.5 microns. One foot in length of such filament therefore has a surface of 1,433,500 square microns, or 1.4335 square millimeters. Taking our data presented in the several tables, where length of fungus content is expressed in feet per cubic millimeter of floc solid, we have only to multiply this value (feet) by 1.43 to ascertain the approximate additional surface in square millimeters added to the one cubic millimeter of solid matter of the floc by the attached fungus filaments.

The actual surface presented by the floc solid will vary greatly, depending on the degree to which the shape of the mass approaches that of a sphere. The substance constituting the floc usually consists of an aggregation of near-geometric forms which, with some allowance, may be classed as cones, cylinders, half-spheres, and spheres. as stated on page 7. Data of representative flocs in nonbulking sludge are tabulated in Table 2, in an attempt to present more concisely the relationship that seems to exist between the volume and the surface area of the floc proper and the volume and surface area added to that same floc by reason of the fungus filaments growing upon it. Inspection of this table will show that nonbulking sludge flocs of representative sizes (see Columns 1 and 2), containing relatively small amounts of fungus growth (Columns 4 and 6), are increased in volume and in surface area by this fungus; Column 9 shows the per

cent of increase in volume, and Column 10 the per cent of increase in surface area. The per cent of volume increase varies from less than 0.1 of 1 per cent to 0.3 of 1 per cent, while the surface area values (Column 10) vary from 3. to 17 per cent. Briefly stated, we have in this nonbulking sludge, a fungus growth sufficient to increase floc volume an average of about 0.2 of 1 per cent, and floc surface area meantime is increased an average of about 9.4 per cent.

Comparison is now in order with similar data of representative flocs of bulking sludge, as given in Table 3. Here it will be seen (Columns 9 and 10) that per cent of increase to the volume of the floc varies from 0.4 of 1 per cent to 1. per cent, while increase to the surface area of the floc is from 23. to 48. per cent. In brief, the bulking sludge has fungus growth sufficient to increase its actual substance (or volume) an average of about 0.6 of 1 per cent, and its surface area is increased meantime an average of about 35 per cent.

It seems significant that we thus have, in this fungus, an organism capable of growth <u>in situ</u>, and likewise capable of producing in the floc an increase of 35 per cent in the surface area, which is in fact the friction surface in contact with the water. If such gain in friction surface does not add, meantime, a weight sufficient to keep the

floc-and-fungus combination on a par, relatively speaking, with the weight of the nonfungous portion of this floc, then the tendency to float must be perceptibly increased. In other words, if this fungus growth decreases the specific gravity of the floc-and-fungus combination, the tendency to float is necessarily increased.

In order to ascertain this approximate relative weight of the fungus as compared with that of the floc substance, the following experiment was carried out.

A beaker of good size (400 c.c.) was selected, and filled to a certain depth (2.5 inches) with distilled water the temperature of which was 29°C., with the specific gravity, therefore, of 0.995971. In a similar beaker was placed a similar depth of water to which a little sodium chloride had been added, making the specific gravity by hydrometer reading exactly 1.000.

1. Into the first beaker was now placed a small mass (2 millimeters in diameter) of the fungus in pure culture. This, wholly immersed in a small amount of water, was handled by a large-mouthed pipette, and was not exposed to air, nor to the surface tension of the water in the beaker, but was very carefully and slowly released just under the water surface. As the fungus mass slowly sank to the bottom, the time required was noted. Then the mass was again

raised by the pipette to the water surface, and again released. This was done five times, care being exercised throughout to allow the water to become free of currents.

2. Into this same beaker we now introduced small amounts of activated sludge floc from three different samples, namely: (a) that which was escaping over the weir at Tenafly when sludge was showing a fungus content of 16.4 ft. per cubic millimeter of floc solid, (b) a sample from the bulking sludge blanket which showed a fungus content of 11.5 ft., and (c) a sample from the sludge blanket of July 23, when bulking was absent, sludge was settling properly, and fungus content of this same sample averaged only 1.4 ft.

In every case, the sludge was well mixed before taking this small amount, and this latter was then deposited *without exposure to air* upon a cover slip fixed in a horizontal position just under the water surface. At a given moment, these floc particles were pushed off the cover slip, and the time noted when they reached the bottom of the beaker. This was repeated several times with each of the three samples mentioned, a new portion of the floc being used each time.

As might be expected, the floc particles of a given sample, of varying sizes and having varying amounts of fungus filaments, did not all fall at the same rate, but tailed out, some falling rapidly, others maintaining a position midway, and still others arriving last at the bottom. The

time intervals stated in the accompanying Table 4 were obtained from such floc as maintained a midway position.

It will be observed that the nonbulking sludge required the least time for settling. This, to be sure, is what we expected, for it is what we find true in plant operation. Again, the bulking sludge requires more time than does the nonbulking, and this too is true in plant experience. The chief item of interest is the fact that the fungus only (without sludge) requires more time for settling than does any of the three sludges, all of which contained some fungus. This being the case, we are warranted in the conclusion that the fungus growing on the floc operates to decrease the specific gravity of the floc-and-fungus combination, thereby increasing the tendency to float.

Small amounts from these four samples (a minute bit of fungus only, and small amounts in turn of well-mixed floc: (1) from effluent going over the weir, (2) from bulking sludge, and (3) from good, nonbulking sludge) were next placed, without exposure to air, just under the surface of the second beaker, which contained liquid of specific gravity 1000 by hydrometric reading. All samples floated at the surface for several seconds, this seeming to indicate that this liquid was too heavy to permit sinking of these substances until these were well saturated by the heavier

liquid. This period of floating was not very accurately determined, but varied from about four minutes for the fungus only to 30 seconds, 23 seconds, and 25 seconds for the floc samples, taken in the order given above.

Returning to Tables 2 and 3, we again refer, in Column 10 of the latter table, to the typical bulking sludge the flocs of which bear sufficient fungus growth to increase the floc area by an average of 35 per cent. We are now able to state that such considerable increase of surface area is effected by the growth of a substance, fungus tissue, which is in effect lighter than the floc substance, as indicated by the longer time required for such tissue to settle in distilled water. Given, then, a slight but continuous movement of the water, as in the clarifier tank at Tenafly,- it is apparently only a question of sufficient fungus growth adding enough of this lighter-than-floc material to produce a floc-and-fungus combination which, with greatly increased friction surface, refuses to settle in the slow-moving water. Such floc meantime requires more room because of the outgrowth of fungus, and accordingly "bulks," changing the one-time sludge blanket into a diffuse cloud of suspended matter intruding into the surface water and escaping over the weir.

In all the observations and data available from the

Tenafly plant, there seems to be no particular change in the normal pH values, regardless of whether the sludge is bulking or not, the usual reading being about 7.0 to 7.3. When lime is used to correct bulking, the pH is temporarily changed thereby, reading about 8.0 or a little higher.

Summary.

Bulking is frequent and troublesome in the activated sludge plant at Tenafly, New Jersey.

Three weeks' observation, and study of daily samples, show:

1. Fungus, chiefly Sphaerotilus, is always present on the sludge flocs, but occurs in very small amounts in the incoming raw sewage.

2. When the plant is functioning properly the fungus growth in the sludge blanket averages only 3.1 feet per cubic millimeter of floc solid. When sludge is bulking the fungus growth in this same place averages 11.3 feet.

3. Indications point to about 7 feet of fungus growth as the beginning of the danger zone, less than 7 feet being rarely accompanied by bulking at Tenafly.

4. Fungus filaments radiating in all directions and in all planes from the floc, increase the volume and the sur-

face area. In nonbulking sludge this volume increase averages 0.2 of 1 per cent and the surface area over 9 per cent. In bulking sludge the respective increases average 0.6 of 1 per cent in volume and 35 per cent in surface area.

5. Surface area added by fungus growth is increased friction surface, functioning in water much as the parachute of thistle seed functions in air. The interrelationships of: (a) amount of friction surface, (b) weight to be lifted, and (c) movement of surrounding medium, appear to be similar in the two cases.

6. According to laboratory tests described on pages 27-29, the specific gravity of the fungus is less than that of the floc proper, hence increase of the fungus contingent will decrease the specific gravity as well as increasing the friction surface, of the floc-and-fungus combination. Pressure of outgrowing filaments on adjacent floc meantime, together with continuous but slow water movement, combine to produce a physical readjustment of the floc particles, these requiring more room as the sludge thus bulks.

DIRECTIONS FOR BRIEF EXAMINATION OF
SLUDGE BLANKET FLOC
TO APPROXIMATE AMOUNT OF FUNGUS PRESENT.

1. Use a glass slide, well cleaned, so that water will spread freely on it.

2. Drop about 3 drops of clean water (tap water will do) on the slide.

3. Thoroughly mix the sample from the sludge blanket, by swinging the bottle in a rotary fashion. Then at once remove a portion with pipette, and drop one drop into the clean water on the slide. Distribute with a needle, if necessary, so the flocs are well separated.

4. Place the slide in the 37°C. incubator to dry. It will be ready for examination in 30 or 40 minutes. If an incubator is not available, place the slide on a warming table, or any warm (not hot) place. Best results are obtained if the slide dries slowly during a period of at least 30 minutes.

5. The flocs, dried down on the glass slide, will be of various shapes and sizes. If fungus is present, they will look something like cuts ——— —— — .

Examine 4 or 5 representative* flocs and: (1) esti-

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* Say 1 fairly large floc, 1 small, and 2 or 3 medium size. Also, select such flocs as have a representative or fair amount of fungus growth, if this is present.

mate the volume of each, then measure approximately the total length of fungus filaments. Use a micrometer disc in the eyepiece of the microscope for these measurements. Record the results of examination something like this:

(1) Floc No.	(2) Volume cu. mm.	(3) Fungus length mm.
1	0.001	4.
2	.004	10.
3	.008	8.

Restatement* of Columns (2) and (3) in terms of one cubic millimeter of floc solid, gives the following:

Floc	(4) Volume of floc solid (cu.mm.)	(5) Fungus length (feet)
1	1	13.1
2	1	8.2
3	1	3.3

*

$$\frac{1.\ \text{cubic millimeter}}{\text{cubic millimeter in floc}} \times \frac{\text{millimeters of fungus in floc}}{305\ (\text{millimeters in 1 ft.})} = \text{Fungus length in feet}$$

The smallest floc (No. 1) shows fungus at the rate of over 13 feet per cubic millimeter of floc solid. This is within the danger zone. On the other hand, floc No. 3, eight times as large as No. 1, does not have eight times as much fungus (see Col. 3) and, placed on an equal basis as to size (Col. 4), the fungus length is only 3.3 feet, a figure well within the safety zone.

Brief examination in this manner of a few representative flocs will indicate whether a majority of them, if any, contains sufficient fungus growth - about 7 feet or more - to indicate probable danger of bulking.

By all means use an eyepiece micrometer. This work should not be attempted without it, as measurements are thereby greatly facilitated.

TABLE 1. TOTAL LENGTH, IN FEET, OF ATTACHED FILAMENTS PER CUBIC M
BASED ON FIVE AVERAGE BLOCKS PER SAMPLE, TWICE DAILY, NEW

Date	Period	Sampling points: 1. Raw sewage	2. Return sludge	3. Mixed sewage and return sludge, at start of aeration	4. Outlet of aeration tank	5B. The "Sludge blanket"	(Depth of blanket under surface)	5T. Effluent at weir of clarifier
July							(Feet)	
31			3.5	3.4		3.1	6	12.1
32		1.8	4.1	3.3		1.6	8	(1) 1.4 (2) 5.2
	I		1.2			.7		
33		trace	1.0	1.6		1.4		2.2
34		trace	2.0	1.3	3.4	1.3		0.8
35			1.6	2.7	2.3	4.1		4.4
36						3.5		0.8 4.3
9:10 AM		trace	5.3	2.5	7.3	13.6		13.4
11 AM	II	trace	4.3	3.3	3.0	6.0		9.3
1:30 PM				2.0	3.8	5.8 7.5	8 3	10.3
4:30 PM				2.1	3.6	6.6 4.9 11.3	3.5 3.3 8	4.6
34	III	none	3.7	2.3	4.7	6.8	7	16.4 8.0
38 10 AM			14.3		1.3	11.3	8 at 10.7 AM 3 " " 10 AM	(a) 13.7 (b) 13.3
4 PM	IV			3.3		10.1	1.5 " 4 PM	10.4
40	V		2.9	2.7	7.2 3.3	4.4	8 AM	20.3 (a) 10.3
41			3.3	2.3	1.7	10.1	3.3 " 10 AM	3.3
AUG. 1	VI		2.4	2.3	1.3	3.4	4.5 at 10 AM	3.4
3	VII		1.8	2.1	4.3	1.3	3 4m AM	3.6

. IN TEST, OF ATTACHED FUNGUS PER CUBIC MILLIMETER OF THE FLOC SOLID.
E AVERAGE FLOCS PER SAMPLE, TEWKSBURY, NEW JERSEY, SLUDGE.

Aeration Tank Outlet	Sludge Blanket	Depth of Blanket (under surface)	Effluent at Weir of Clarifier	Use of Lime Began	Use of Lime Ended	Remarks
		(Feet)				
	3.1	6	12.1			
	1.6	8	(1) 4.4 (2) 5.2			The second sample was taken 1 foot under the water surface.
	..7					
	1.4		3.0			
3.4	1.3		9.8			Sampling Station No. 4 started.
2.3	4.1		4.4			
	3.5		8.8 4.3			
				7/27 11 AM		
7.3	13.8		33.4			Sludge bulking.
3.0	6.0		8.3			Use of lime begun at 11:00 A.M. and continued until morning of 7/28.
8.8	2.8 7.8	2 5	13.5			
3.8	6.8 4.8 11.3	3.5 3.5 5	4.8			
4.7	6.8	7	16.4 9.0		7/28 8 AM	
4.8	11.8	8 at 7 AM 8 " 10 AM	(a) 13.7 (b) 13.3	7/28 3:45 PM		(a) Regular sample (b) Floc "as is" gently settled on glass slide.
	18.1	1.5 " 4 PM	18.4			Sludge bulking. Lime used. 3:45 P.M. 7/28 until A.M. of 7/30. See effect of lime in changed depth of sludge blanket.- 1-1/2 ft. to 8 ft.
7.7	7.4	8 AM	30.3		7/30 8 AM	
2.8			(a) 13.5			(a) Floc "as is" settled gently on a glass slide.
4.7	15.8	5.3 at 10 AM	24.2			
4.8	13.8	1.8 at 10 AM	13.8			Lime used.
4.3	1.8	8 " 4n AM	3.8			
8.2	3.3		7.2			

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22			4.1							
			1.2			..7				
	I									
23		trace	1.0	1.6		1.4			3.0	
24		trace	2.0	1.3	3.4	1.3			9.6	
25			1.6	2.7	2.3	4.1			4.4	
26						3.6			6.6 4.0	
										7/27 11 AM
27 10 AM		trace	5.3	2.5	7.3	13.6			33.4	
11 AM	II	trace	4.5	3.3	3.0	6.0			9.3	
1:30 PM				6.0	6.8	5.8 7.3	2 3		13.3	
4:30 PM				3.1	3.6	6.6 1.9 11.3	3.5 3.5 2		4.6	
28	III	none	5.7	3.3	4.7	6.8	7		16.4 9.0	
29 10 AM			14.3		1.3	11.3	3 at 7 AM 3 at 10 AM		(a) 13.7 (b) 13.3	7/28 3:45 PM
4 PM	IV			3.3		18.1	1.5 at 4 PM		18.4	
30	V		2.9	6.7	7.7 3.8	8.4	8 AM		20.3 (a) 13.3	
31			3.3	8.3	4.7	15.9	3.3 at 10 AM		33.3	
Aug 1	VI		3.4	6.3	1.3	33.4	1.3 at 10 AM		13.3	
2			1.6	2.1	4.3	1.9	2 at 10 AM		3.0	
3	VII		1.0	3.3	3.3	3.3			7.2	
	I, III, V, and VII		2.38	3.32	3.9	3.14				2.66
			2.6	6.15	5.77	11.3				17.06

	1.6	8	(1) 4.4 (2) 5.2			The second sample was taken 1 foot under the water surface.
	..7					
	1.4		3.8			
3.4	1.2		2.6			Sampling Station No. 4 started.
2.3	4.1		4.4			
	6.8		3.6 4.8			
				7/27 11 AM		
7.3	13.6		13.4			Sludge bulking.
3.0	6.0		9.8			
8.6	9.8 7.8	2 5	13.5			Use of lime begun at 11:00 A.M. and continued until morning of 7/28.
3.8	6.6 4.9 11.3	3.5 3.5 5	1.6			
4.7	6.8	7	16.4 9.0		7/28 8 AM	
4.8	11.3	8 at 7 AM 8 " " 10 AM	(a) 13.7 (b) 13.3	7/28 3:45 PM		(a) Regular sample (b) Floc "as is" gently settled on glass slide.
	18.1	1.5 " 4 PM	16.4			Sludge bulking. Lime used, 3:45 P.M. 7/28 until A.M. of 7/30. See effect of lime in changed depth of sludge blanket,- 1-1/2 ft. to 5 ft.
7.7 1.8	..4	8 AM	30.3 (a) 13.5		7/30 8 AM	(a) Floc "as is" settled gently on a glass slide.
.7	13.8	5.5 at 10 AM	8.8			
.3	38.4	4.8 at 10 AM	3.6			Lime used.
.5	1.8	4 4n AM	3.0			
.2	3.3		7.2			
8	3.14		3.66			Unbulking sludge.
77	11.3		17.06			Bulking sludge.

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TABLE 2. FLOC OF NOVEMBER SLUDGE.

	The individual floc				On the basis of one cubic millimeter of floc solid					
	1	2	3	4	5	6	7	8	9	10
							Surface area		Per cent added by fungus filaments	
No.	Volume	Relative size	Surface area	Length of fungus	Number of flocs required	Length of fungus	Of flocs	Of * fungus	To volume	To surface area
	cu. mm.		sq. mm.	mm.		feet	sq. mm.	sq. mm.		
1	0.00058	1.	0.0314	0.8	1933	3.	60.4	7.1	0.3	12.
2	.00188	3.3	.064	1.3	617	3.6	38.3	5.1	.2	9.8
3	.0023	4.4	.169	3.	435	3.6	73.5	4.	.2	5.
4	.00264	5.1	.115	1.7	379	3.1	43.6	3.	.1	7.
5	.00364	7.	.185	2.4	275	3.2	51.	3.1	.3	6.
6	.0051	8.8	.126	.8	197	0.5	25.2	.7	.03	3.
7	.0073	13.8	.31	7.9	140	3.6	29.4	5.1	.2	17.
8	.008	15.4	.368	11.6	124	4.7	44.9	6.7	.3-	15.
								Averages	.2	9.35

* Fungus is 1.5 microns in diameter. The volume is therefore 0.00054 cu.mm., and the surface area is 1.4356 sq.mm. per foot of length.

Data of individual flocs of various sizes in Columns 1-4 are, for convenience, restated (Columns 5-8) on the basis of one cubic millimeter of floc proper, together with the pro rata fungus which would accompany such floc, and the resulting additions (Columns 9, 10) to the volume and to the surface area of this floc.

TABLE 3. FLOC OF BULKING SLUDGE.

	The individual floc				On the basis of one cubic millimeter of floc solid					
	1	3	3	4	5	6	7	8	9	10
No.	Volume	Relative size	Surface area	Length of fungus	Number of floc required	Length of fungus	Surface area of floc	Surface area of fungus	Addition to floc by fungus filaments Volume (per cent)	Addition to floc by fungus filaments Surface area (per cent)
	cu. mm.		sq. mm.	mm.		feet	sq.mm.	sq.mm.		
1	0.00053	1.	0.0314	3.	1923	16.9	60.4	27.	1.	45.
2	.00134	2.4	.074	5.6	801	9.5	59.2	13.6	.5	23
3	.00335	4.5	.165	10.3	433	14.4	70.1	30.6	.8	29
4	.00897	5.7	.133	10.6	336	11.6	45.4	16.6	.6+	36
5	.0031	6.6	.147	12.2	296	11.8	43.8	16.9	.6+	39
6	.0047	9.	.246	13.4	212	8.6	58.3	12.3	.5-	23
7	.0072	13.6	.326	22.9	139	10.9	45.3	15.6	.6-	34
8	.0082	15.6	.193	19.9	122	8.	33.5	11.4	.4+	48
								Averages	0.625	34.9

Data of individual floc of various sizes in Columns 1-4 are, for convenience, restated (Columns 5-8) on the basis of one cubic millimeter of floc proper, together with the pro rata fungus which would accompany such floc, and the resulting additions (Columns 9, 10) to the volume and to the surface area of this floc.

TABLE 4. AVERAGE TIME REQUIRED FOR TWO SETTLING OF FUNGUS ONLY, AND FOR FLOC FROM BULKING AND FROM NONBULKING SLUDGE, IN A LABORATORY TEST, USING DISTILLED WATER AT 20°C.

Fungus only (about 2 mm. in diam.)	Floc from bulking sludge:		Floc from nonbulking sludge
	(1) Passing over weir	(2) From sludge blanket	
Seconds	Seconds	Seconds	Seconds
95	48	33	35

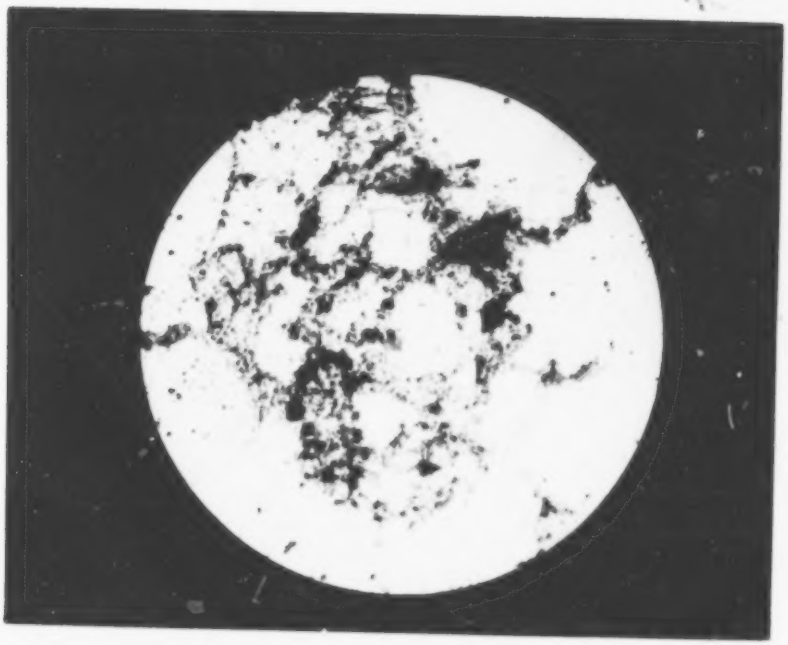

Fig. 1. A sludge mass, or raft, with interpassing fungus filaments, all in the original undisturbed condition except that it is all in one plane. This mass was 2 mm. long. About half of it is shown, the large square representing 1 sq. mm. on the microscope stage. (From bulking sludge.)

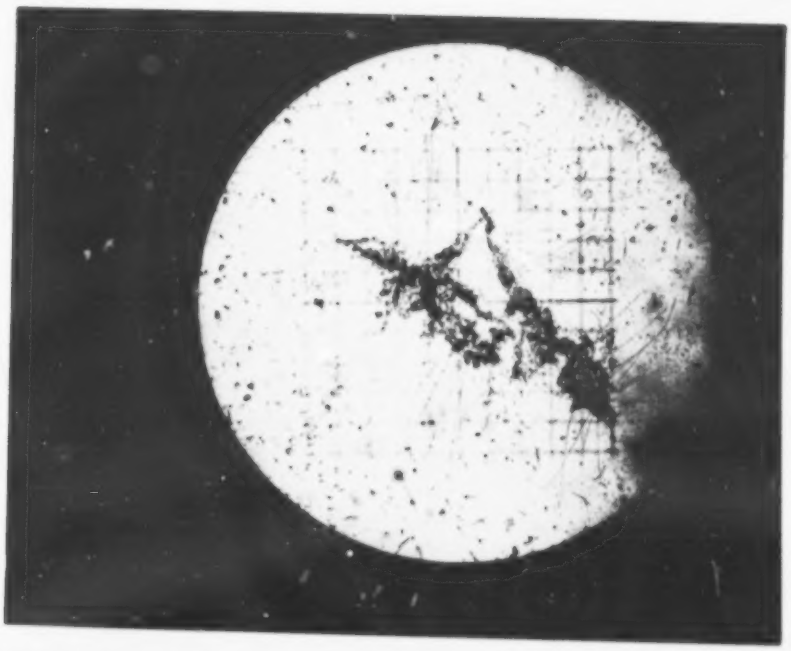

Fig. 2. Flocs from bulking sludge, obtained at same time and place as was the sludge mass in Fig. 1, but the flocs were separated by agitation and dilution. Note the out-growing fungus filaments.

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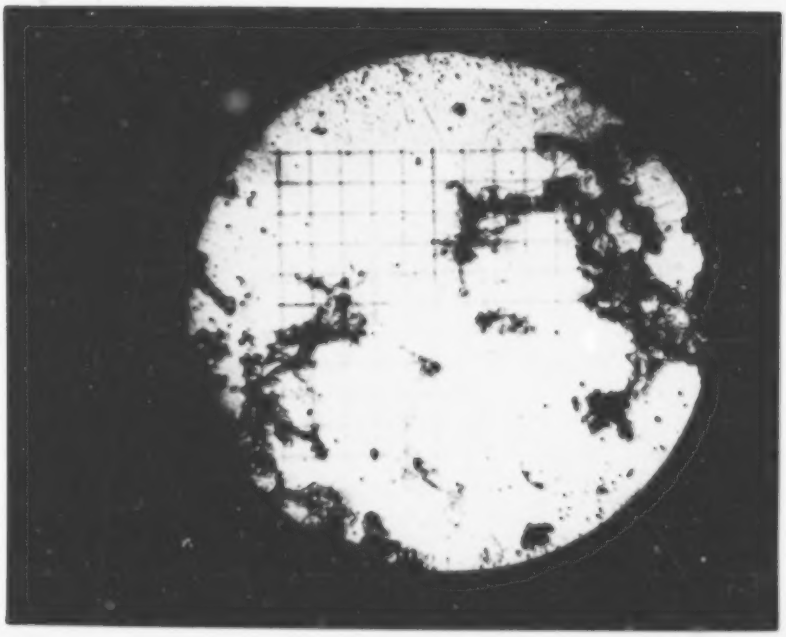

Fig. 3. Sludge masses, showing possible interference and interpassing of fungus filaments from adjacent flocs. The apparently hopeless tangle separates readily on agitation and dilution. From bulking sludge.

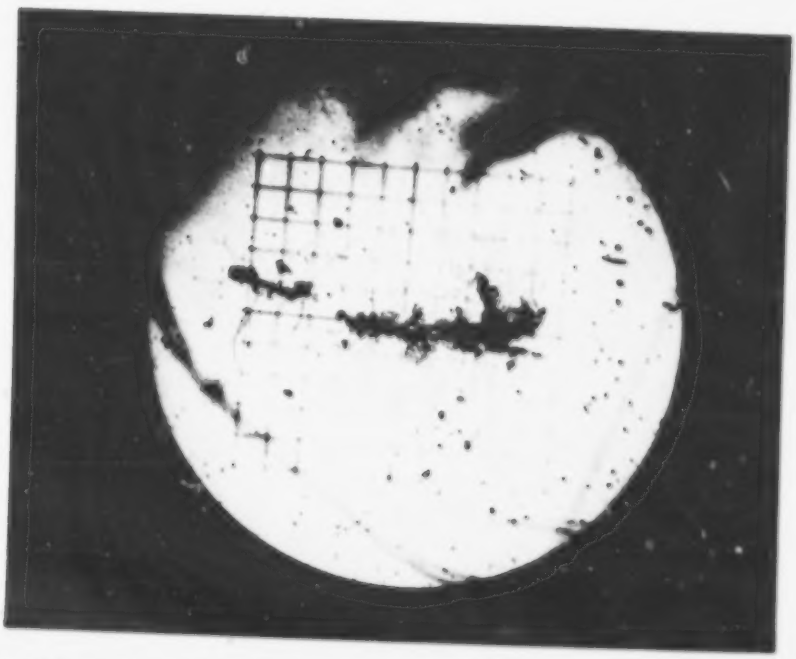

Fig. 4. The larger floc measures .0037 cu. mm., and the fungus filaments total 16.5 mm. in length. This is at the rate of 14.6 ft. per cu.mm. of floc matter. From bulking sludge.

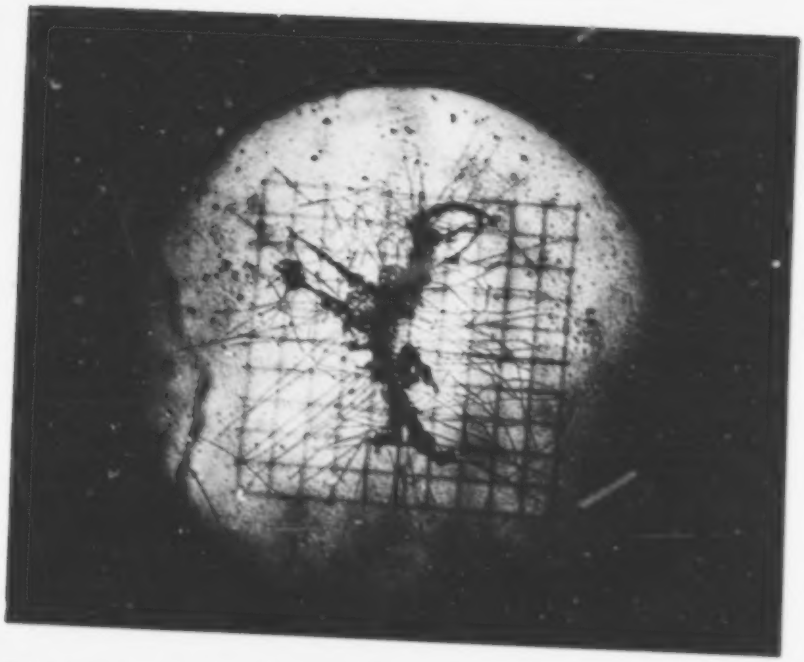

Fig. 5. This floc, nearly 1 mm. long, measures .0045 cu.mm., and its fungus filaments have a total length of 38.5 mm., or about 28 ft. per cu. mm. of floc matter. From bulking sludge.

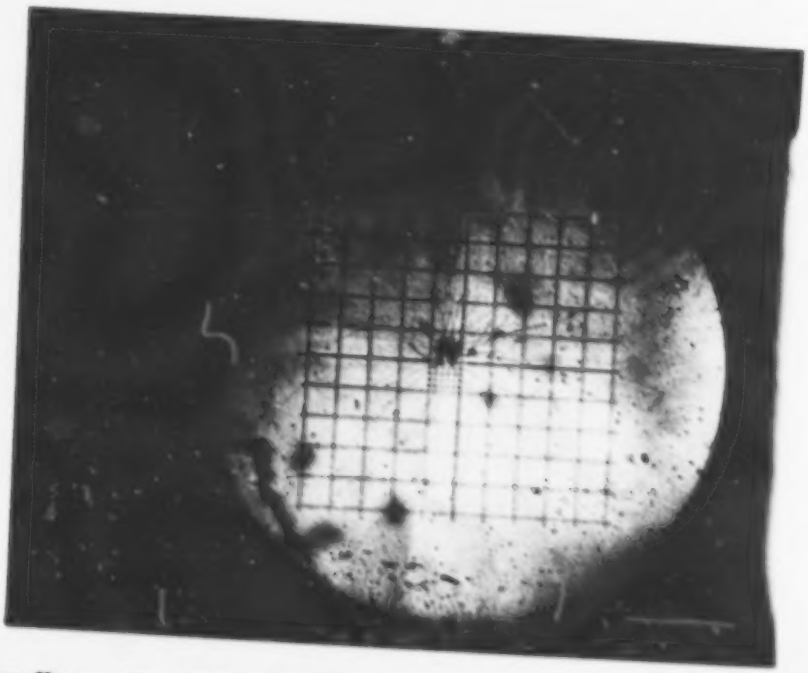

Fig. 6. This tiny floc, less than 0.1 mm. in greatest diameter, and measuring .00038 cu.mm., yet has a large number of long filaments of fungus totaling 14.5 mm. making its relative fungus content very high--125. ft. per cu.mm. of floc matter. From bulking sludge.

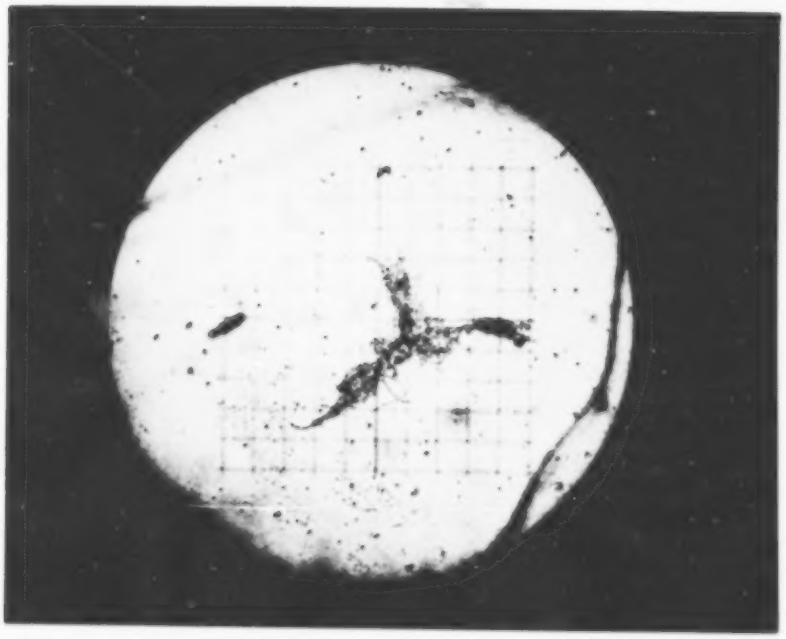

Fig. 7. This floc, from non-bulking sludge, measures .0034 cu. mm. and is comparable in size to that shown in cut 4, but the fungus content, 2.5 mm., is only 2.4 ft. per cu. mm. of floc matter.